University of Southern Queensland

Faculty of Health, Engineering & Sciences

Evaluation of Remotely Piloted Aircraft in Surveying Applications

A dissertation submitted by

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Abstract

Over recent years Remotely Piloted Aircraft (RPA) have become highly accessible to civilians. This presents many significant opportunities to surveyors, by giving them the chance to combine the science of photogrammetry with a personal, portable and self-piloted aerial platform.

But despite the obvious opportunities, many questions still linger. It must be remembered that this technology is vastly different from the technologies that are currently at most surveyor's disposal, i.e. GNSS, total stations, laser scanners, and LiDAR. RPA are accompanied by a range of unique considerations. How fast and how far can they fly? What weather conditions can they operate in? What are the laws and regulations involved? And most importantly, how does all this impact on how they can be used for surveying?

The aim of this project was to answer these questions by evaluating the performance of an RPA after using it for a survey. First, an evaluation plan is outlined that is focused on determining the overall practicality of using an RPA in a specific surveying application—in this case, the determination of coal stockpile volumes. Several evaluation criteria are specified: efficiency, accuracy, usability and legal requirements.

An RPA is used to survey a coal stockpile area and its performance is analyzed using the evaluation plan. The accuracy of the resulting DTM, and the efficiency of the RPA is analysed by comparing its results, against the results of the same survey performed with a terrestrial laser scanner (TLS). Usability is also assessed on a comparative basis with the TLS, using the system usability scale (SUS). The relevant statutory regulations are also studied and the impact of these regulations upon surveying activities is explained.

The results show that the RPA is more than suitable for coal stockpile surveys. Accuracy and efficiency are comparable with that of a TLS, however the most significant benefits are those which have not been quantified—those being the significantly enhanced job safety; significantly reduced physical labor requirements and a greatly simplified workflow.

Although these results satisfy the aim of the project, it is recognized that the results can be improved by altering the evaluation criteria or process, or by taking an entirely new approach. A number of suggestions are discussed and included as recommendations for future research.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

21/10/2013

Date

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Glossary of terms

DTM
Acronym for Digital Terrain Model.

Digital Terrain Model
A three dimensional surface (defined in X, Y and Z) rendered by a computer which represents the topography of a particular area.

Measured value
A number obtained (i.e. distance, angle, coordinate, etc.) through measurement that may contain gross, systematic or random error.

Residual
The difference between a measured value and its true value.

RPA
Acronym for Remotely Piloted Aircraft.

Remotely Piloted Aircraft
An aircraft that is capable of operating without an on-board human pilot, either autonomously or through the use of remote control.

True value
A number representing the real measurement (i.e. distance, angle, coordinate, etc.) as it physically exists, free of the gross, systematic or random error that is introduced by the act of measurement.

UAS
Acronym for Unmanned Aerial System.

Unmanned Aerial System
In this document, Unmanned Aerial System is the same as “Remotely Piloted Aircraft”.

UAV
Acronym for Unmanned Aerial Vehicle.

Unmanned Aerial Vehicle
In this document, Unmanned Aerial Vehicle is the same as “Remotely Piloted Aircraft”.

CHAPTER 1

Introduction

1.1 Introduction and background

> *"Like a lot of military innovation… highly advanced UAV – both fixed wing and helicopter – is starting to come into the financial and technical reach of many UK geomatics and surveying companies. But just what legal and technological issues do these evolving pieces of kit raise in our fast paced geo-industries? Has the use of UAV/UAS outstripped the appropriate aviation authority legislation? What about privacy issues? Security issues? And as a tool for surveyors? Just how good is the resultant mapping, imagery and data capture, usability and accuracies?"*
>
> --James Kavanagh, Director RICS Land Group (June 2013)

James Kavanagh's words resemble a question that many Spatial Scientists are asking themselves today, as more and more Unmanned Aerial Systems (UAS) (or Remotely Piloted Aircraft) make their way into the hands of civilian users:

How can I use a UAS? *Can* I use a UAS?

At first, the answer seems obvious. Of course surveyors can use UAS; after all, aerial photogrammetry has proven to be a powerful and a reliable method of data capture. But it is not the science of photogrammetry that must be questioned; it is the platform itself. James Kavanagh's words highlight a number of considerations that must be made before a surveyor uses a UAS, including: legislative requirements; its usability, ease of use and efficiency; what it takes to produce high quality, accurate data. These are all important questions, and many of the answers can change depending on the specific type of UAS used and what it is being used for.

Consider the current situation in the United States. The commercial use of UAS is struggling due to strict legal restrictions, and a sensitive social debate about the privacy and security issues when it comes to using UAS. In fact, as of the 7th of August, only two UAS have been approved for commercial use in the United States (Haldane 2013); previously such use was simply not allowed.

In contrast, Australia's UAS legislation enables the commercial use of UAS by anyone who is adequately certified. In fact, there are currently 49 commercial UAS Operator Certificates in Australia (CASA 2013a). The future of UAS systems in Australia appears bright in comparison to other countries such as the USA.

While the political drama surrounding UAS is not the focus of this dissertation, the political and legal debates serve to highlight the important fact that UAS are completely different from the other tools that surveyors regularly use. They are accompanied by a wide range of new and unique considerations, with statutory regulations being only one of them.

There are many surveyors who are left answerless or overwhelmed by these considerations. What are the legal implications? Will the UAS be more efficient than the equipment I have now? Will the UAS provide the accuracy I require? Do the benefits outweigh the costs? For many surveyors, the potential benefits of using a UAS are painfully obvious—but their actual capabilities are still unclear, as is the case for many new technologies when they are being introduced.

But when it comes to using a UAS, there is not a constant answer to any of those questions, which is a result of the broad range of factors that must be considered. The number of "surveying grade" UAS that are available today is surprisingly large, and they all offer different levels of functionality. And as it has been alluded to; their potential applications are vast.

Because of this, UAS technology cannot be judged using one factor alone, nor can they be assessed with respect to a single function or application. Simply put, what one surveyor deems to be a severe limitation, could be a mild inconvenience for another. Furthermore, when one specific model of UAS is unusable in a certain application, another model might offer vast increases in productivity and job safety.

Based on this idea, the work presented herein assumes the position of a surveyor who is considering a UAS as their next surveying instrument. The factors that should be considered while making such a decision are recognized and researched. Then, an attempt is made to place these factors into a logical and systematic process for evaluating a UAS, so that the benefits of using it can be identified—thus allowing a decision to be made about using that particular model of UAS.

To achieve this, the principles and tools used by many adaptable evaluation plans have been researched, and an evaluation has been described that is used to assess the performance of a UAS in several critical areas, specifically:

1. Its efficiency and productivity in the desired surveying application
2. Its ability to achieve the required accuracy and precision
3. Its usability (i.e. how easy it is to use)
4. The legal responsibilities of the UAS operator

By evaluating the performance of a UAS in each of the above areas, the benefits of using a UAS can be identified. Of particular interest in this project is determining the benefits of using a UAS for coal stockpile surveys. As such, the methodology and analysis of the results has been centralized around this application. However, the overall "evaluation plan" has a broader focus—it is not limited to a single surveying application (i.e. coal stockpiles). In this way, the evaluation techniques used in this project may be carried across to other projects that seek to learn about the benefits of using a UAS in a separate application.

Using this evaluation plan, a number of conclusions are made about using a UAS for coal stockpile surveys and the use of UAS for surveying in general, and a number of recommendations are made. However, there are a number of things that can, or should be improved about the evaluation techniques used in this project, if adopted in future research. These are recognized in the final chapters of the dissertation and are emphasized heavily in the recommendations for future research.

1.2 Aim

The broad aim of this project is:

1. To recognize the critical factors impacting the use of a Remotely Piloted Aircraft (RPA), so that the benefits of using an RPA for coal stockpile surveys can be identified and evaluated, and thus if it should replace the current method of survey.

1.3 Objectives

The aims of the project are fulfilled by completing the following objectives:

1. Carry out a literature review aimed at identifying and understanding:

    i. the most common uses of UAS technology in surveying; and,

ii. the various consumer features and physical characteristics of commercial UAS that are used in surveying applications; and,

iii. the various factors that are known to impact the performance of UAS technology in surveying applications, or the factors that impact the accuracy of photogrammetry and how these are accounted for (or not) when using UAS; and

iv. the legal requirements of using UAS.

2. Based on the research from the literature review, determine the various factors that may impact a surveyor’s decision to use a UAS.
3. Research the principles of an effective evaluation.
4. Determine how each of those factors from (2) can be evaluated to determine their impact on the performance or usability of a UAS.
5. Prepare an experiment to compare the eBee UAS with a terrestrial laser scanner for coal stockpile surveys, by writing the methodology for performing a coal stockpile survey with the eBee UAS and a terrestrial laser scanner.
6. Perform the coal stockpile survey and use the evaluation techniques identified in (4) to assess the performance of the eBee UAS compared against the terrestrial laser scanner.
7. Based on the evaluation from (7), recommend if the eBee UAS should replace the current method of survey or not.

1.4 Project outline

The literature review of this project is focused on establishing the need for an evaluation, providing background on some of the equipment and ideas, and justifying the methods that have been used. A significant portion of the review is dedicated to research of the critical elements of an evaluation, and developing the evaluation plan that guides the rest of the project.

It also outlines the main characteristics of the UAS technology that is available today and summarizes some key features. It reviews some of the important considerations for performing an aerial photogrammetric survey to maximize the quality and accuracy of the results.

A significant portion of the review is also dedicated to summarizing the Civil Aviation Safety Regulations (CASRs), in an attempt to better understand and evaluate their impact upon the use of UAS in Australia.

The middle chapters of this project are concerned with applying the evaluation plan outlined in the literature review, to determine the benefits of using a specific model of UAS in a specific application. This project has been sponsored to evaluate the "eBee" UAS, and determine the benefits of using it for performing Coal Stockpile Surveys.

To achieve this, the eBee is compared against the current method of survey; a terrestrial laser scanner (TLS). The TLS is used as the baseline to determine the accuracy, efficiency and usability of the eBee. Chapter 3 (methodology) outlines the two methods of survey and describes how the data was processed and reduced.

The results chapter (chapter 4) is heavily focused on analysing the accuracy of the data collected by the eBee. However, this chapter also includes a section which analysis the efficiency of the eBee, and describes some significant considerations concerning ease-of-use (or usability). These considerations include safety; labor requirements; the intuitiveness of the software interface; and the ability to check data in the field.

Chapter 5 (discussion and recommendations) is focused on bringing all of the results and information together and driving it all towards a conclusion. First, each factor is discussed individually (accuracy, efficiency, usability and legal requirements) before considering all of these elements together to reach a final recommendation about using the eBee for coal stockpile surveys.

This chapter is rounded off by discussing the success of the evaluation plan that had been outlined in chapter 2, and used to guide the collection and analysis of information throughout the project. The evaluation's shortcomings are recognized and ways to improve the process are suggested.

The conclusion (chapter 6) follows, which provides a brief summary of the results, an outline of the projects key outcomes and makes suggestions for future research.

1.5 Scope, limitations and ethical considerations

1.5.1 Scope and limitations

This work is carried out purely in the context of surveying and spatial science applications. It is recognized here that a UAS does have a large variety of applications outside of surveying and spatial science (i.e. surveillance and monitoring), but they are not considered in this project. Specific focuses for this project are:

1. The professional and legal implications of using UAS in Australia
2. The efficiency and ease-of-use of a UAS
3. The accuracy of a UAS when performing coal stockpile surveys

Additionally, the applicability of this research will change over time. While this is a fact for nearly all work involving evaluation, it requires special consideration here due to the subjects being evaluated. UAS technology is rapidly improving, and legislation is always being altered. Once these changes occur—especially changes to legislation—some research gathered in this project will become irrelevant. This should be kept in mind whilst reading the legal and technical content.

1.5.2 Ethical considerations

A number of ethical questions have also been considered while writing this dissertation. Of course, the most immediate danger when performing an evaluation is forming a bias opinion. Presenting false or subjective information as fact is always unethical, but that danger is even more prevalent for this type of work.

It must be considered that this project aims to evaluate a product (UAS) which is being marketed towards a specific group of people. The outcomes, which will either be positive or negative, may influence people's decision to use this product. As such, the following considerations have been kept in mind during writing:

1. A responsibility towards UAS manufacturers and distributors to take a cautious, systematic and objective approach to evaluation, and not write material that negatively impacts the reputation of their products.
2. A responsibility towards consumers to take a cautious, systematic and objective approach to evaluation, and not write false material that makes the UAS appear more capable than it really is.
3. A professional responsibility to carry out the evaluation in a manner that is ethical, thorough and consistent.

CHAPTER 2

Literature review

2.1 Introduction

This literature review seeks to provide background and justification for the project itself, and the survey equipment and methodology that has been used. First, Unmanned Aerial Systems (UAS) are defined (section 2.2), and their history is explained in order to provide the reader with some background to explain where UAS currently stand in society and the reasons behind some of their controversy. In addition, some commercial UAS and their main applications are described to provide the reader with a cross-section of the technology that is currently available. This is followed by a section (section 2.3) dedicated to outlining the major differences between different models of modern UAS, and explaining how these differences provide different advantages and disadvantages.

One specific model of UAS—the eBee UAV—is then singled out and described in detail (section 2.4). This is because the eBee is the model of UAS evaluated in Chapter 4. This section provides the background and specific technical details that user must be familiar with to be able to use the eBee and evaluate its performance.

Following this is a review of evaluation processes (section 2.5). The purpose of this section is to define what an evaluation is, and define the context and purpose of the evaluation for this project. The next section (section 2.6) outlines the crucial elements of the evaluation plan, and describes the indicators that are used to evaluate UAS performance in this project.

Following this is a basic review of the factors that influence the accuracy of photogrammetry (section 2.7). The purpose of this section is to demonstrate that the accuracy of aerial photogrammetry is influenced by many factors; unlike other survey methods where the instrument and the method alone are the two critical factors influencing accuracy. This is followed by a section describing the process of assessing the accuracy and quality of a DTM (section 2.8), which is necessary to support the analysis in chapter 4.

The regulations controlling the use of UAS in Australia are then described (section 2.9) in order to provide an understanding of how these laws impact the practicality of using a UAS for surveying. Specific attention is paid to the cost incurred, and the effort required by the surveyor in order to satisfy these requirements.

2.2 Unmanned aerial systems

This section introduces unmanned aerial systems by defining the relevant terminology and providing a brief history of their development. The current level of UAS uptake in Australia is discussed, and the level of professional acceptance is described. In order to provide some perspective on the current level of UAS technology available, a number of existing models are described and their potential applications are listed.

2.2.1 What is a "UAS"

Unmanned Aerial Systems (UAS) - also called unmanned aircraft, unmanned aerial vehicles, remotely piloted vehicles, remotely piloted aircraft or drones - are machines capable of flying without a human pilot on board. A UAS may still be controlled directly by a human pilot by the use of a remote control, or it may be an entirely autonomous system capable of piloting itself (TheUAV.com n.d).

A common example of a UAS is a radio controlled toy model airplane. However, in the modern era more sophisticated UAS are being employed as solutions to a number of survey related problems in a variety of industries. One such UAS is the "eBee", developed and produced by the company *senseFly* (SenseFly 2012), which is discussed in more detail in section 2.4.

To surveyors, UAS represent an airborne platform for remote sensing. There are a variety of UAS that are marketed specifically as survey instruments, which are normally fitted with a digital camera which is capable of taking high-resolution photos of the terrain or objects that the UAS is flying over.

These systems contain all of the electronic components and sensors the enable it to be programmed for photogrammetry missions. Missions can be fully planned using dedicated software, and the flight paths can then be uploaded onto the UAS CPU. If the mission is executed properly, the resulting photographs can be used in stereophotogrammetry from which digital elevation models can be derived.

2.2.2 The history of UAS

The thought of a remotely piloted or self-piloted aerial vehicle has been lodged in the minds of aviators and engineers since humans first took flight. However it is difficult to pinpoint when experimentation and development first really began. Technically the first UAS were balloons which were first experimented with in 1782 (Tetrault 2013), and used as aerostats and weather monitors.

However - like many sophisticated technologies – much of the early history of UAS (as we know them today) takes place in the military. UAS which were able to be guided and controlled accurately enough to be used practically, may not have gone under significant development until the World War I era (WWI) (Cox et al. 2004) when America and Germany began developing attack drones. Both the US and Germany met very limited success when developing primitive 'aerial torpedoes', which were limited to a single preset trajectory (UAVM n.d). These projects were plagued with technically difficulties and funding issues; most were closed not long after WWI.

During World War 2 (WWII) (1939) more “serious” attempts were made to develop UAS for military use (Cox et al. 2004). A UAS called the “Interstate BQ-4” (Fig. 2.1) was developed by the US and used in a number of successful missions against the Japanese (Tetrault 2013). It was essentially an aerial torpedo (or ‘suicide drone’), that was guided into targets through the use of a radio control and a video feed from a nose-mounted camera. But due to the limited technological resources of that time period, the BQ-4 had a number of technical issues. Its development was very low priority and it was halted after WWII.

Figure 2.1: A photo of an Interstate BQ-4 in operation
Source: U.S. Naval Aviation News 1946

After WWII (1945) many of the US UAS research programs were again abandoned. But, it wouldn’t take long for research to restart when the Cold War (1947-91) and the Vietnam War (1955-1975) again spiked the demand for technology. To avoid casualties in Vietnam, America developed a number of UAVs specifically designed for reconnaissance (exploration/investigation) missions

(Cox et al. 2004). Most notable was the Ryan Firebee series; the first jet propelled UAS to ever be produced and put to practical use as a surveillance UAS (Tetrault 2013).

The Firebee spurred the interest of the US military, inspiring it to continue its research even after the Vietnam War came to a close. The tactical UAV "MQM-105 Aquila" started development in 1979, but it was laden with many technical and financial difficulties. Out of 105 test flights, the Aquila completed only seven successfully (U.S. Army 2010) and so the project closed down in 1987 (Cox et al. 2004).

By the 1970s, Israel was making its own attempts to develop a UAS for offensive and reconnaissance use. In 1982 the Israelis led the most successful UAS program of any nation so far. They used UAS to great efficiency, to defeat the Syrian Air Force by using them as attack drones, decoys, radar jammers and surveillance units (Cox et al. 2004; Tetrault 2013). Many regard this event as the beginning of the modern era for UAS

After Israel's impressive victory, UAS developed rapidly and the US began experiencing its own success. In 1991 UAS played an important tactical role in the "Desert Storm" conflict on the Persian Gulf. In 1995 the "MQ-1 Predator" (Fig 2.2) UAS was introduced, and has since become the most commonly used UAS by the U.S. Air Force and Central Intelligence Agency (CIA). It has had extensive use throughout the middle-east including Pakistan, Afghanistan and Iraq. It is a remotely piloted aircraft, and is able to be outfitted with a variety of remote sensors and weapons (U.S. Air Force 2012).

Since the Gulf War, the U.S. has deployed UAS during every conflict it has been involved in (Tetrault 2013). And after finally achieving success in the military, UAS began finding their way into the civil sector. But due to UAS still being extraordinarily expensive towards the end of the 1990s, their use was largely limited to well-funded researchers, government organisations and large corporate companies. Among their first uses in the civil sector include monitoring and security. For example, since 2004 the United States Department of Homeland Security has been using UAS as surveillance tools for border security (CBP Today 2004).

Figure 2.2: A predator drone.
(Herrman 2009)

Currently the term “UAV” or “UAS” is common knowledge amongst the general public. This is due in part to the controversial debate surrounding their use in both the military and civil sector. Many people are concerned about the morality of using UAS as offensive weapons, as there have been a number of instances where their use has resulted in the death of civilians (Epatko 2011).

Unfortunately, as UAS grows in popularity in the civil sector, the controversy deepens and the need for appropriate control escalates, with many concerned about privacy and safety. Without a human pilot, UAS are deficit on spatial awareness, and so are at risk of colliding with other aircraft, buildings and people (Collins n.d.). These concerns have resulted in many controls and restrictions being put in place to govern the use of UAS in civil airspace.

Evidently, UAS have had limited publicity as a reliable remote sensing platform, and has experienced limited use in surveying applications which fueled the concerns over their limitations. However, organisations such as the Australian Civil Aviation Safety

Authority (CASA) recognize the potential of UAS and understand the need to adapt regulations as UAS become safer and more accessible to the general public. The future of UAS appears to be bright so long as their usefulness and acceptance continues to improve.

2.2.3 Country and professional context

The previous section revealed that drone technology is the subject of social and political debates around the world. This is primarily the result of their use in the military, and rising concerns over safety and privacy. The debate is currently at its peak within the United States of America, after the American Congress ruled the Federal Aviation Authority (FAA) to write rules that would allow the commercial use of UAS in American National Airspace.

Until August 2013, no method of certification existed for people who wished to operate a UAS for commercial purposes within the American National Airspace System (NAS). Even now, only two UAS are approved for use. The situation in America is a perfect reflection of the criticisms and legal barriers that exist for UAS in many parts of the world.

However, the situation in Australia is vastly different. Legislation for the use of UAS has existed since October 2001 (CASA 2013c), and the commercial use of UAS is achievable by acquiring the appropriate certification from the Civil Aviation Safety Authority (CASA). Because the Australian government has avoided simply outlawing UAS, Australia has been referred to as one of the most UAS friendly countries in the world (Garcia 2013).

In Australia, surveyors are being actively encouraged by professionals and their institutions to use this technology. As of September 2013 there are 49 registered UAS operators in Australia, using the UAS for surveying applications (CASA 2013a). Additionally, UAS have featured in a number of conferences hosted by the Surveying and Spatial Sciences Institute (SSSI) including the annual Surveying and Spatial Sciences Conference 2013 (SSSI 2013a).

Although concerns still exist for privacy and safety within Australia, the commercial use of UAS for surveying is not out of the question in any sense. In fact, the professional use of UAS within Australia, for experimental purposes and commercial gain is already occurring. But the uptake can be vastly improved by providing prospective users with a way to answer the simple question of "should I use a UAS instead of my GPS, total station or laser scanner?"

2.2.4 UAS options for private users and their applications

There are now a number of UAS available to private industries in Australia, which are suitable for surveying and mapping applications. Here, some of the more popular and modern UAS are described providing a good cross-section of the available technology. This section also demonstrates how the size, weight, endurance, wind resistance, photo quality, and various other physical features vary significantly between each model. Later it will be explained how each of these characteristics might have an impact on how the UAS can be used. Note that this list is not exhaustive; it is only intended to be demonstrative of the current level of UAS technology that is available.

Pteryx UAV

The Pteryx UAV (Fig. 2.3) is designed, manufactured and marketed by the Polish company "Trigger Composites". It represents the larger and more robust category of modern UAS. It must be launched from a catapult or similar device, making it not as transportable as other, lighter UAS. The head of the Pteryx is rotatable, so that the sensing device (i.e. the camera) can be oriented to take orthogonal or oblique photographs – a unique feature among today's UAVs.

Figure 2.3: A flying Pteryx UAV
(Trigger Composites 2013)

The Pteryx comes in two variants, however the Pteryx "Pro" is the model designated for surveying and mapping applications. The specifications of the Pteryx Pro are (Table 2.1):

Table 2.1: Pteryx Pro Specifications

Wingspan	2.4 metres
Weight	5.0 kilograms
Camera	N/A (user supplies).
Endurance	2 hours of flight time
Cruise speed @ altitude	45-55km/h @ typical altitude of 250m
Wind resistance	25km/h
Maximum coverage area	4-6km squared in one flight
Photo resolution	Depends upon the camera.

As mentioned above, the Pteryx Pro is marketed as a surveying instrument, with specific applications in (Trigger Composites 2013):

- Photogrammetry
- Environmental surveys
- Precision agriculture
- RPA research

PAMS

Figure 2.4: The PAMS UAV
(SmartPlanes 2010)

The Personal Aerial Mapping System (PAMS) (Fig. 2.4) is among the lighter and more transportable models available today. It has been developed by Smart Planes, a Swedish company who also manufactures and markets the PAMS (SmartPlanes 2010). The main selling point of the PAMS is that it is light, and is able to be launched by hand. It comes with all the necessary software to plan a flight mission and process the data. The specifications of the PAMS are described in Table 2.2.

The PAMS is marketed as a surveying instrument with its main applications described as (SmartPlanes 2010):

- Watershed surveys
- Mine surveying including stockpile surveys

- Resource stockpiles including log piles and gravel

Table 2.2: PAMS Specifications

Wingspan	1.2 metres
Weight	1.1 kilograms
Camera	10MP digital camera
Endurance	0.5–1.5 hours of flight time
Cruise speed @ altitude	0.84km/h @ 200m altitude
Wind resistance	Not specified.
Maximum coverage area	0.25-0.5 kilometers squared
Photo resolution	5cm per pixel at 200m altitude

Gatewing X100

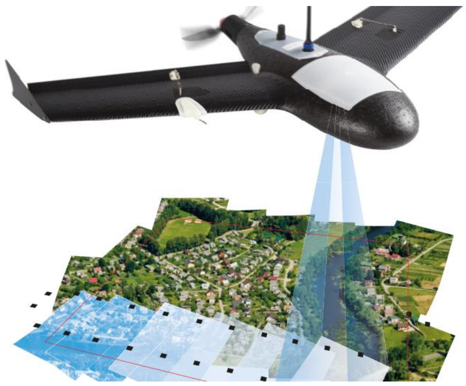


Figure 2.5: A depiction of the Gatewing X100 UAV
(Gatewing 2013)

"Gatewing" is a Trimble company (Gatewing 2013) designing, manufacturing and selling the X100 UAV (Fig. 2.5). The X100, although not as bulky as the Pteryx, requires a catapult to launch.

The main attraction of the X100 (if the surveyor owns other Trimble equipment) is that it is ultimately a Trimble product, allowing its operation to be integrated with other Trimble equipment and software. The Gatweing X100 is marketed specifically as a surveying instrument for mapping and DTM generation, with stated "accuracies" of 5cm horizontal and 10cm vertical.

Table 2.3: X100 Specifications

Wingspan	1 metre
Weight	2.2 kilograms
Camera	10MP digital camera
Endurance	0.75 hours of flight time
Cruise speed @ altitude	80km/h @ 100-750m altitude
Wind resistance	65km/h
Maximum coverage area	1.5 kilometers squared
Photo resolution	5cm per pixel at 150m altitude

Quest UAV

Figure 2.6: The Quest UAV
(QuestUAV 2013)

Quest UAV is a British company designing, manufacturing and marketing several models of UAV (QuestUAV 2013). The two main models are the Quest 300 and Quest 200 (Fig. 2.6), which offer different levels of functionality. The Quest 300 has a larger wingspan and is able to carry a larger payload (i.e. 2 cameras), while the Quest 200 is smaller, more transportable and more of a "standard" UAV with a single digital camera setup.

The Quest UAV is marketed as a surveying instrument with the following applications noted (QuestUAV 2013):

- Land management data
- DTM generation for engineering works
- Road and rail infrastructure mapping
- Mining and stockpile assessments

Table 2.4: Specifications of Quest UAVs

	Quest 300	**Quest 200**
Wingspan	2 metres	1.5 metres
Take Off Weight	4kg	3.3kg
Camera	Options include NDVI camera, thermal, multi-spectral or standard 10.1MP digital camera. The 300 can mount two cameras simultaneously.	10.1MP digital camera
Endurance	1.5 hours	1.5 hours
Cruise speed @ altitude	Avg. 64km/h	Avg. 64km/h
Wind resistance	64km/h	64km/h
Maximum coverage area	1 kilometers squared	1 kilometers squared
Photo resolution	1cm per pixel (flying height unspecified)	1cm per pixel (flying height unspecified)

Swinglet Cam

The Swinglet Cam (Fig. 2.7) is among the smallest UAVs available today, with a weight of only 500 grams. This makes it super transportable and able to be launched by hand. The Swinglet cam is produced by a Swiss company called SenseFly, and comes with all of the necessary software to plan missions and process photographic data (SenseFly 2013a).

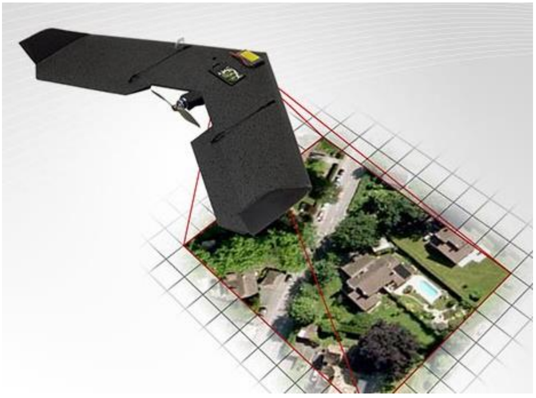


Figure 2.7: The Swinglet Cam UAV
(SenseFly 2013a)

Among other uses the Swinglet Cam is marketed as a surveying instrument, advertised with specific applications in:

- Mapping and GIS
- Environmental Management
- Conservation work
- Forestry mapping

Table 2.5: Swinglet Cam Specifications

Wingspan	0.8 metres
Take Off Weight	0.5 kg
Camera	16MP digital camera
Endurance	0.5 hours of flight time
Cruise speed @ altitude	36km/h
Wind resistance	25km/h
Maximum coverage area	1.5-6 kilometres squared
Photo resolution	3cm to 30cm per pixel

2.3 Physical characteristics and features of UAS

The previous section demonstrated how UAS can differ significantly in physical characteristics and features. Here, those physical characteristics and built-in features of modern UAS, and the impact that they may have on performance or ease of use are examined more closely.

2.3.1 Size and weight

The size and weight of the UAS may have an impact on transportability and safety. Generally speaking, the larger the UAS the less transportable it is, and the greater the risk of personal injury or property damage if it were to collide with someone or something (CASA 2002).

The Civil Aviation Safety Regulations (section 2.9) defines three categories of UAS based on their size and weight:

1. *Large UAV, which can be a:*
    a. *Unmanned airship with a capacity greater than 100 cubic metres*
    b. *Unmanned powered parachute with a launch mass greater than 150 kilograms*
    c. *Unmanned aeroplane with launch mass greater than 150 kilograms*
    d. *Unmanned rotorcraft (such as a helicopter) with a launch mass greater than 100 kilograms*
    e. *Unmanned powered lift device (aircraft with flaps, slats etc. intended to increase lift) with a launch mass greater than 100 kilograms*
2. *Micro UAV, with a gross weight of 100 grams or less*
3. *Small UAV, which is any UAV that isn't a micro or large UAV*

Most commercial UAS are defined as Micro or Small UAVs (i.e. those outlined in section 2.2.4), which do not carry any specific restrictions under the Civil Aviation Safety Regulations. This would indicate that the size and the weight of the aircraft is more of a convenience factor, but it may impact practicality if the UAS needs to be carried for long distances. However, the more significant concern when it comes to the weight of the aircraft is its take-off and landing style.

2.3.2 Take-off and landing style

Take-off and landing style is an important consideration as this may limit where and how the UAS can be used. Different UAS have different requirements in terms of open space in order to take-off and land safely. Some large UAS will even require a run way in order to take off and land.

The UAS available today can be divided into two major categories: rotary UAS (i.e. helicopter type UAS) and fixed wing UAS. Each have their own advantages and disadvantages. Fixed wing UAS can be further divided into two subcategories based on their take-off styles. You have the smaller UAS which can be launched by hand, and the larger models that require a catapult or similar type of mechanical launch device. Each of these continue to have their own advantages and disadvantages.

Fixed wing aircraft

The UAS outlined in section 2.2.4 are all fixed winged aircraft. Compared to rotary UAS, fixed wing models generally have the following advantages:

- They are faster and cover more ground.

- They are generally lighter and easier to operate.
- They are mechanically less complex.

But also have the following disadvantages:

- Require a larger area to take-off and land.
- Cannot hover/observe a single position for any period of time.
- Less overall maneuverability (i.e. can only travel in a horizontal direction at a fixed velocity).

Fixed wing launched by hand

Light UAS such as the PAMS or the swinglet CAM (section 2.2.4) have the ability to be launched by hand. This is normally an advantage of their light weight. Generally, these aircraft are so light that they are rarely considered a safety hazard, and it means that there is no need to transport bulky launch devices, which can be seen as an advantage. These types of UAS normally require a shorter take off distance, which is a significant advantage over larger fixed wing UAS, when they have to be launched in an enclosed space, such as an open-cut mining pit.

Fixed wing launched by launch device

Larger UAS such as the Pteryx or the Gatewing (section 2.2.4) require a launch device (Fig. 2.8) in order to achieve the velocity necessary to become airborne. These “catapults” come with the obvious disadvantage of becoming another bulky device to carry in the field. They also represent a safety hazard, with the obvious risk of catapulting the UAS into someone or something at a relatively high velocity (15m/s for the Gatewing).

Figure 2.8: The Gatewing UAS fixed to its catapult, ready to launch
Photo by Wikipedia user Alainq

These larger UAS come with some significant advantages though. They are generally much more stable and are able to withstand much higher wind velocities. This means that the UAS can be operated in poor conditions and a good output can still be achieved. Larger UAS are also capable of longer flying times and therefore a greater range; they are able to cover much more ground than the lighter, hand-launched UAS or the rotary type UAS.

Fixed wing requiring a runway

As mentioned earlier some very large UAS may require a runway in order to take-off and land. These have extended benefits including being able to cover much larger areas; having much greater flight stability and being able to carry much larger payloads (i.e. including LiDAR scanners and multispectral cameras). However, they have the obvious disadvantages of only being able to take-off and land on a suitable runway, and as such have limited usability and transportability. They also represent a more significant safety hazard in the event of a malfunction or emergency landing.

Vertical Take-Off and Landing (VTOL)

Rotary UAS are an entirely separate class of UAS. There are many different styles of rotary UAS, and are normally categorized by the amount of propellers/blades they are fitted with. Some "helicopter" style UAS exist (i.e. a single blade), but there are more complex systems on offer such as "quadrocopters" (i.e. four blades) and "octocopters" (i.e. eight blades). Different configurations offer different advantages in terms of stability, maneuverability, speed, battery life and payload.

Rotary type UAS offer a number of significant advantages over the fixed wing models, including:

- They are able to take-off and land vertically, which means they can be operated in very tight, enclosed areas.
- They are capable of hovering over a single position for extended periods of time for monitoring or surveillance purposes.
- They have enhanced maneuverability; they can be moved in a horizontal or vertical direction easily, which means they can be guided into areas which might not be visible from the birds-eye view of fixed wing aircraft.
- Rotary type UAS can be configured with many more propellers or "lift devices" which means they can be designed to have significantly more lift, and therefore carry much greater payloads.

But come with some of the following disadvantages compared to fixed wing aircraft:

- Mechanically, they are much more complex and therefore more susceptible to mechanical difficulties and much more difficult to fix.
- They are generally slower than fixed wing UAS and are not capable of covering as much ground.
- With no wings they do not have the capability to glide to a safe landing zone in the event of a malfunction.
- They are generally heavier than the small UAS used in surveying. When this is combined with their inability to glide, they pose a much more significant safety risk in the event of a malfunction.

2.3.3 Endurance and maximum coverage area

This is a relatively simple physical characteristic that can have a low or significant impact on the efficiency of a UAS, depending on the intended application. The "endurance" of a UAS describes how long it can stay airborne; this is essentially its battery life. The "coverage area" is the theoretical maximum area that can be photographed or surveyed by a UAS during one flight (i.e. before the battery is depleted), taking into account its endurance and average flying speed.

The coverage area may have an impact on the efficiency and usability of a UAS. The smaller the maximum coverage area, the more frequently the UAS must be grounded so that the battery can be replaced on larger surveys. This will also become a problem when the UAS has to survey large, inaccessible areas such as dense forestry or open canyons. If the UAS is limited in range, only a portion of the area can be flown.

2.3.4 Wind resistance

The wind resistance describes the maximum wind speed that the UAS can be flown in. In high wind speeds, the platform will become unstable and the sensor will not be able to operate as accurately. Safety will also become a concern when wind speeds exceed the wind resistance of the aircraft, which will increase the risk of a crash or a collision.

This is obviously a significant consideration in some areas with high average wind speeds. Even generally, this will be a significant consideration with the weather ultimately dictating when the UAS should or should not be used.

2.3.5 Sensor type or payload

UAS can be fitted with a variety of different sensors. The predominant sensor type is the standard digital camera, but the sensor size and pixel resolution vary between different UAS. It is recommended that the largest possible pixel resolution is used in order to maximize the ground resolution of the photographs and therefore maximize the point-sampling distance for point cloud generation. This will improve the quality and accuracy of any map or digital terrain model (DTM) that is produced with the UAS.

Some larger UAS—particularly rotary (helicopter) type UAS are capable of carrying LiDAR or multi-spectral sensors, and a variety of other attachments. Some UAS (such as the Quest UAV from section 2.2.4) may not have the ability to carry such large sensors but can carry multiple smaller sensors (i.e. digital cameras). This functionality can be used to significantly increase photo redundancy (an important consideration in flight planning, discussed in section 2.4 and 2.7).

2.3.6 Sensor orientation

One significant feature that exists on some UAS is the ability to alter the camera orientation. Most fixed wing UAS only provide an orthographic camera orientation. However, some UAS exist (such as the Pteryx UAS) that allow the sensor's orientation to be altered so that oblique photographs can be captured as well.

2.3.7 Safety features

As explained in preceding sections, safety is a significant concern when using UAS, especially in civilian airspace. Most governments and aviation authorities have laws and regulations in place, that specify minimum safety requirements for UAS design before they can be used in controlled airspace. The Australian Civil Aviation Safety Authority (CASA) has made some specifications regarding (CASA 2002):

- Collision avoidance systems
- Abort or emergency landing procedures, or flight termination procedures which operate as a "fail-safe" to navigate the UAS to a pre-determined recovery area in the event of an emergency
- Automatic emergency protocols and procedures in the event of:
    - Engine failure
    - Loss of data link/communications with the UAS
    - Loss of control
    - Navigation errors or "failure"
    - Damage to the UAS while it is in the air
- Lighting/LED for enhanced visibility

- Materials for weight and strength

Some UAS manufacturers may include additional safety features in their designs, which include:

- Manual flight termination
- Parachute release
- Audible warning alarms for technical issues

So although safety is an important part of using a UAS, and there are a number of safety features available, it will not be included in this evaluation—as it extends well beyond the scope of this project.

This is because, in Australia's case, CASA has already prescribed the minimum safety requirements for commercial UAS. These requirements must be met before the UAS can be operated in Australian airspace—or the UAS must obtain a certificate of airworthiness from CASA.

As such, if the UAS under evaluation meets those requirements set by CASA and it has been approved for civilian use, then "safety features" are not really a concern for the surveyor. The surveyor's primary concern in terms of safety is meeting their requirements under the Civil Aviation Safety Regulations (described in section 2.9), which is to ensure that they operate the UAS in a safe and secure manner at all times; ensuring that they do not cause harm or injury to anyone or thing.

2.4 Evaluation subject: the eBee

This section describes the model of UAS that is used and evaluated for surveying coal stockpiles in this project. The "eBee" UAS is described and its specifications are outlined so that it may be compared with other models mentioned previously. The process for planning a flight with the eBee is outlined with considerations on how to optimize data quality.

2.4.1 The eBee design and specifications

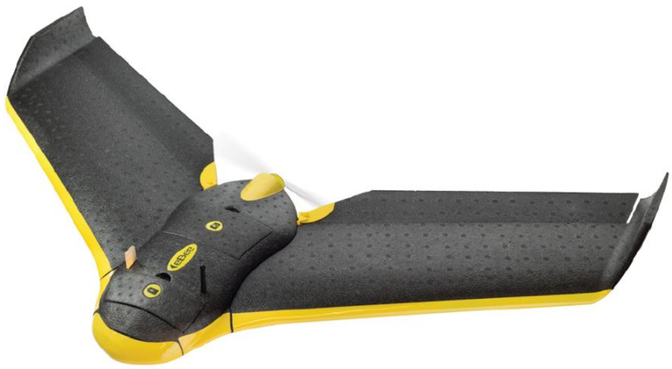


Figure 2.9: The eBee UAV

The eBee (Fig. 2.9) is classified as a “small UAV” under the current *Civil Aviation Safety Regulations 1998*. This UAS is marketed as a surveying implement, which is capable of performing aerial surveys and producing high-accuracy maps and digital elevation models (DEM). The eBee may be classified as a middle-tiered model in terms of size and endurance, amongst the current options available for fixed wing UAS. Specifications of the eBee are described below (SenseFly 2013b):

- Wingspan: 96cm
- Weight: 670g
- Camera: 16 megapixel digital camera
- Endurance: 45 minutes of flight time

- Cruise speed: 40-65km/h
- Wind resistance: up to 45km/h
- Maximum coverage area: 10km squared
- Nominal precision: 5cm

2.4.2 Preparing a flight plan with the eBee

The first step in any aerial photogrammetric mission, large or small, is the preparation of a flight plan. In traditional aerial photogrammetry, flight plans were prepared using a simple topographic map (USQ 2012). Knowing the flying height; camera characteristics (such as photograph dimensions, focal length/principal distance, aperture settings etc.); flight speed; the required photo overlap (forward and side); and the size of the area to be photographed, important planning information could be derived, including:

- The number of flight lines (the resulting rows of photographs are commonly referred to as “strips”) required; and,
- the number of photographs to be taken; and,
- how long the flight will take.

This information is still critical in today’s planning, including that for autonomous UAS. However, in the case of the eBee, this planning is carried out in a purely digital environment with software performing all of the necessary calculations. The flight plan can be easily designed and saved, and then uploaded directly onto the eBee’s computer which uses the data to guide itself and record photos autonomously.

Although the process has been automated, there are still a number of important decisions that the UAS controller (human) must make.

This includes flying height (which legally cannot exceed 400 feet or approximately 122 metres), overlap, and the decision to include perpendicular flight lines.

Flying height

The flying height affects a number of other parameters including the area captured per photograph and the ground resolution. Higher flying heights capture a greater area per photograph, which results in less photographs being required for the mission which saves flying time and processing time, thus resulting in greater economy. For a small UAV this is important, because battery life is limited. However, a higher flying height also results in lower ground resolution, which will decrease the accuracy of the final digital terrain model (DTM) (Eos Systems Inc. 2013; USQ 2012).

However, it is suggested that the flying height be set at the maximum legal limit (400 feet AGL) to minimise the possibility of running out of battery life. Based on the eBee's camera parameters this will provide a photo resolution of approximately 3.8 centimeters per pixel which is more than sufficient for coal stockpile surveys. Refer to section 2.7 explaining how this will affect accuracy.

Overlap

Having adequate overlap is critical for stereophotogrammetry. This is because only the overlapping sections of the photographs can be used to form a stereoscopic model, from which height data can be derived. This means that each photograph will need to be completely overlapped by other photographs in order for a DTM to be produced, thus requiring an absolute minimum of 50% longitudinal (forward) overlap (Fig. 2.10).

However, compared to larger aircraft, small UAS are very unstable platforms that are highly susceptible to drift (i.e. being pushed away from the flight path by wind). Considering this instability, the overlap should be considerably higher than the 50% minimum. A value of 70% is recommended by the eBee manufacturer. Lateral overlap must also be included, and this is recommended to be at 60%, ensuring full photographic overlap (SenseFly 2013b). Greater overlap will also increase the accuracy of the processing by ensuring that ground control points (GCPs) and terrain features appear on multiple photographs; greatly assisting the aero-triangulation process.

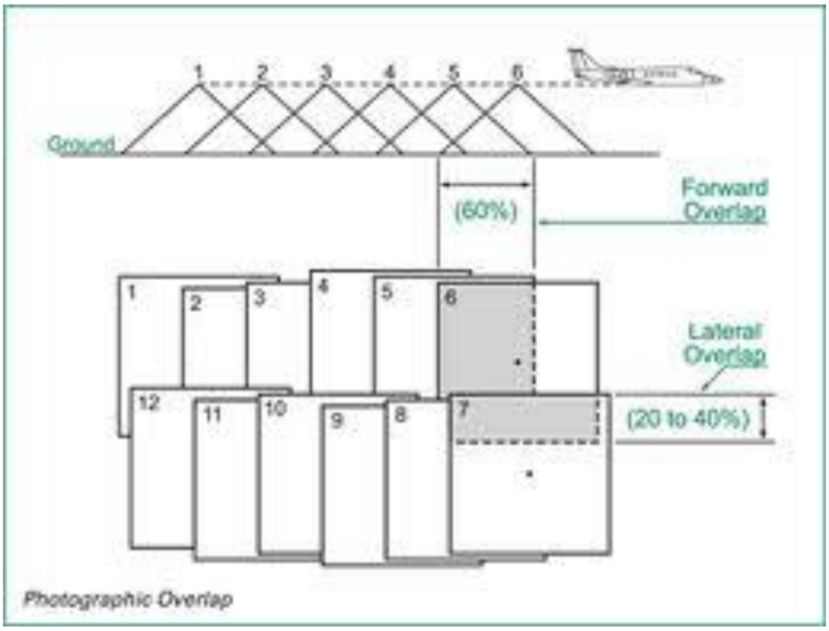


Figure 2.10: A diagram explaining photographic overlap. Aerial surveys with full-sized planes usually use less photographic overlap because of greater platform stability.
By Indiana Geological Survey

Perpendicular flight lines

The decision to include perpendicular flight lines (Fig. 2.12 and 2.13) is based upon the features that need to be mapped.

Photogrammetric heighting measures parallax, which only occurs when an object appears in two different photographs from two different perspectives. If an object such as a tall building is flown over in only one direction, then only two of the walls will be modeled, because only two of the walls will be visible in the photographs (assuming the flight line is perpendicular to the walls of the building) (Fig. 2.11).

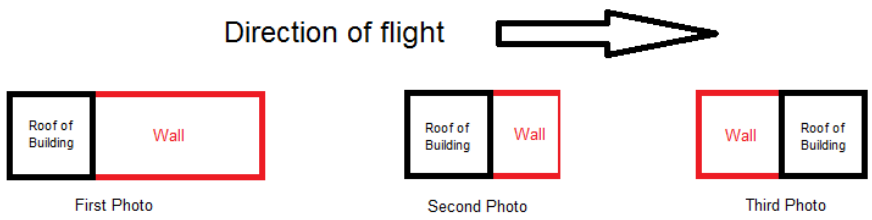


Fig. 2.11: In this diagram the flight line is perpendicular to the east-west walls of the building. This means that no elevation data can be obtained for the north-south walls unless perpendicular flight lines are used.

If the terrain is flat and steady, then there is no need to fly perpendicular flight lines. However, if sudden changes in elevation occur, then perpendicular flight lines will be required to ensure that all surfaces are modeled. Coal stockpiles generally have a variety of steady slopes and steep inclines and therefore it will be necessary to use perpendicular flight lines to model them correctly.

To create the flight plan, the designated overlap and flying height requirements are entered into the eBee's planning software (eMotion 2), and perpendicular flight lines are selected. Satellite imagery is then used to select the area to be flown, by drawing a rectangle around the desired area. Flight paths are then calculated automatically, ready to be uploaded to the eBee.

Figure 2.12: The straight red lines show the flight path of the UAV. Currently, there are no perpendicular flight lines included in the flight plan.

Figure 2.13: Perpendicular flight lines have now been included in the flight plan. Obviously, the flying time is increased by introducing perpendicular lines. To avoid power loss, the eBee must land and have its batteries changed before flying the perpendicular lines.

2.5 Evaluation planning: need and context

An evaluation is a process carried out to provide an objective and systematic review of a particular process, project, system, etc. In this case, the process in question is a new "work procedure" that utilizes the UAS as the primary tool. Such an evaluation involves examining the UAS performance on several different qualitative and technical levels.

The aim of this section is to establish the need for such an evaluation, define its scope and describe the types of evaluation that are possible. Doing this provides the groundwork for creating an evaluation plan, which is discussed in the following section (section 2.6).

2.5.1 Defining the purpose and context of the evaluation

Simple evaluations may be carried out without requiring a specific plan or objective. But for more complex evaluations it is necessary to specify criteria which will guide the research and provide scope for the discussions (NSW Government 2011e), avoiding the following risks:

- A risk of wasting time and resources by performing unnecessary research that does not contribute to the purpose of the evaluation.
- A risk of discussions becoming off-track, irrelevant and subjective because of the lack of criteria guiding the assessment.

Exactly what kind of evaluation is performed and how it is carried out depends upon the process or equipment being evaluated. That is, the method and criteria of the evaluation vary significantly between different models, depending on what is being evaluated and why (Glenaffric Ltd 2007; NSW Government 2011e).

Therefore, when planning an evaluation it is important to first understand the desired result, i.e. what information that needs to be learned from the evaluation—otherwise the process will lack focus, and the results will lack meaningful relevance (Glenaffric Ltd 2007).

Only by defining the context of the evaluation, the drivers (i.e. the motivation behind performing the evaluation), who will use the information and the "type" of evaluation, can suitable criteria (i.e. specific objectives or areas to be assessed) and performance indicators (i.e. how success in each criteria will be measured) be selected (NSW Government 2011d).

Evaluation context

UAS can be used to perform a number of tasks, and evaluations can be carried out for a number of different purposes that are all closely related, therefore evaluations that are not properly contextualized can go off-track quickly. Defining the context of the evaluation provides a reference point for the investigation, and ensures that the evaluation plan remains focused on the task and purpose of interest. If this is done properly then broad, generic and unhelpful evaluation criteria are avoided (NSW Government 2011d).

Two key components to contextualizing an evaluation are the purpose and scope (NSW Government 2011d). In relation to UAS, the purpose defines who will use the information, how it will be used and what benefit it will provide in relation to decision making.

Reiterating the aim of the project from Chapter 1, the purpose of the evaluation is to identify the factors that impact the performance of a UAS, the benefits that the UAS may provide to a surveying operation or business, and thus the practicality or appropriateness of using that UAS for a specific application (in this case the survey of coal stockpiles).

There are some important terms from this description of the evaluation's purpose that will assist in defining the scope. These are:

- Surveying
- Operation or business
- UAS
- Appropriateness
- Practicality

The key words pointed out above summarise the scope of the evaluation. The first key work: "UAS", defines the main subject of the evaluation. If information cannot be related to the evaluation of the UAS, then it should be avoided.

Secondly, the term "surveying" emphasizes that the purpose of the evaluation is to understand how well a UAS performs in the field of Spatial Science—exclusive of all other industries the UAS might have applications in.

"Operation or business" emphasizes that the evaluation's focus is not purely on the technical concepts and methodology of surveying with a UAS. The information that is gathered during the evaluation should contribute to an understanding of how the UAS can practically benefit companies and businesses that practice Spatial Science, and if it is viable to use in a working environment.

"Appropriateness" and "practicality" are terms describing the aim of the evaluation and therefore context within which the information gathered during the evaluation will be interpreted. That is, the information garnered by the evaluation should contribute to an understanding of how the UAS is appropriate, in a practical sense, for use in a specific surveying application.

Evaluation Drivers: why is an evaluation needed?

A "driver" is the motivation behind performing an evaluation. Identifying and describing these drivers identifies the need for the evaluation, and enables a better understanding of the stakeholders and the type of evaluation that is required (NSW Government 2011d).

Drivers can be external or internal. External drivers are enforced by external events or organisations outside of the evaluator's control, for example equipment producers and providers; government organizations; legislation, and so on. Internal drivers are more flexible as they are generally under the evaluator's control. They may include company policies; business aims; existing and future contract conditions, and so forth (NSW Government 2011d).

External Drivers

<u>CASRs</u>

The Civil Aviation Safety Regulations (CASRs), discussed in detail in section 2.9, is a significant driver for the in-depth evaluation of a UAS. This is because acquiring legal certification is a lengthy and sometimes costly process, which may deter many small businesses from adopting UAS. However, it is a process that must be followed if UAS is to be used for commercial purposes. As such, an evaluation plan that properly considers the CASRs will provide the evaluator with information regarding:

- The process they must follow in order to legally use the UAS for their desired application.

- An idea of the cost and effort required to complete this process.
- Details regarding the UAS and the surveying operation that are necessary for gaining certification.
- The benefits of using a UAS so that the cost and the time involved with certification can be justified.

By performing an evaluation that focuses on these points a decision can be made about pursuing certification (i.e. if the time and money investment should be made), and the exact details of the certification process will be known.

Internal Drivers

Internal drivers may vary depending upon the organization, but some common factors exist. Surveying firms are professional organisations that are not only concerned with making a profit, but also upholding professional values and conducting themselves within a code of ethics. Drivers can be found within each of these concerns.

<u>Professional responsibilities</u>

Professionally, a surveyor would perform the evaluation of UAS capabilities because of their responsibility to provide for, and maintain their position within the community (USQ 2013), by providing a professional service. This means a high quality and efficient service that provides accurate and high quality data that is fit for purpose. Many surveyors are skeptical of the ability of a UAS to provide this, but an evaluation of the capabilities and benefits of a UAS will provide an answer that is more substantial than pure skepticism and may even prove the contrary.

A surveyor will also be motived by their responsibility to abide by a code of ethics, for example; the SSSI Code of Ethics which are based upon, among other things, the value of innovative practice, upheld by the professional's support and participation in the continuing development of Surveying and Spatial Science (SSSI 2013b). These codes not only reinforce the professional responsibility discussed above, but also imply that surveyors are encouraged to embrace and use new technologies, and develop new survey methods.

Business operations

Professional and ethical behavior is crucial to the success of a business and client relations, however there must be an adequate cash flow to support the business' activities. Not only is profit important for the proprietor to make a living, and for the company to make a profit, but an inadequate cash flow can also have a detrimental effect on work quality and therefore professionalism (USQ 2013). As such, a significant internal driver for performing an in-depth evaluation of UAS capabilities is concerned with the efficient and profitable operation of the business.

2.5.2 Information uses

It is necessary to point out how the information gathered from the evaluation is intended to be used. Table 2.6 explains who the users of the information may be, and how they may utilize it (NSW Government 2011d). As identified in the section 2.5.1, this evaluation is aimed at surveyors and surveying applications. However, other groups identified in Table 2.6 can use the information in a number of ways.

It is important to identify the different people who may hold an interest in the results of the evaluation (i.e. the stakeholders). By considering how the results may affect them, or how they might use the information, more appropriate criteria and indicators may be selected that enhance the usefulness of the evaluation framework and the benefits it provides (NSW Government 2011d).

Table 2.6: Ways to utilize information gathered from an evaluation of UAS in surveying applications

Information users	Potential ways to utilize information
Surveyors	• Use the results of UAS accuracy and efficiency to make decisions regarding which applications the UAS is suitable for. • Identify the strengths and weaknesses of the UAS in terms of ease-of-use and physical limitations, enabling a comparison with other instruments and survey methods. • Fully understand the capabilities of the UAS so that the surveyor may convey their reasoning for using or not using a UAS to peers and clients. • Use the data garnered by the entire evaluation to make a decision about acquiring legal certification.
UAV distributors	• Determine the strengths and weaknesses of a UAS so that it may be more effectively marketed. • Determine potential client groups by understanding the applications that the UAS is most suitable for.
UAV manufacturers	• Determine areas of improvement for the design or construction of UAS for surveying.

2.5.3 Type of evaluation

Classifying the evaluation is another way of defining the evaluation's key elements. Defining evaluation "type" offers these specific advantages (NSW Government 2011d):

- Provides the evaluator with a way to focus on the purpose of the evaluation and its key elements; and,
- provides an understanding of what the evaluation will deliver, i.e. a progress report, a SWOT analysis, a comparative summary, etc.; and,
- provides the basis for designing the evaluation and defining information needs.

Evaluation "types" are defined by considering the nature of what is being evaluated and the "timing" (i.e. before, during or after an event) of the evaluation (Glenaffric Ltd 2007). For example; acquiring a UAS and using it to achieve a particular objective or create an enterprise is a process that can be divided into three distinct stages, as described in Fig 2.14. At each stage, a different evaluation can occur. These stages are described on the next page (Glenaffric Ltd 2007; NSW Government 2011d).

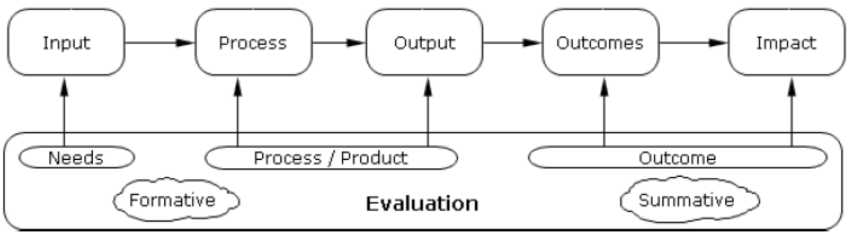


Figure 2.14: The small boxes (i.e. input, process, etc.) describe the elemental steps of any process. The large box identifies the different types of evaluation that may occur at each step.
(Glenaffric Ltd 2007)

1. Needs or Appropriateness
    - The first stage occurs before any action is taken, i.e. before the UAS is purchased. An evaluation at this stage is concerned with identifying the need for the equipment, or identifying its appropriateness. It will identify the aims and objectives of the proposal, any potential benefits and/or detriments, potential ethical or moral issues, and the overall extent to which the proposal will achieve the aims and objectives. Although this review is tied to the "first stage", it might be conducted again after implementation if circumstances change, to ensure the need or appropriateness still exists.
2. Outcomes or efficiency
    - The second stage occurs during implementation, i.e. while the UAS is in use. An evaluation at this stage is concerned with identifying if implementation is occurring properly and/or in the best possible manner. It will identify if processes are being executed correctly, and if these processes are achieving the desired effects.
3. Impact or effectiveness
    - The third stage is a review stage and is normally conducted once the new process or the new methods have been firmly implemented. An evaluation at this stage is concerned with identifying if the aims or desired outcomes have been achieved. It will identify any unintended effects/results, the benefits and detriments that actually occurred against what was expected in stage one, and the overall extent to which the newly implemented technology has actually achieved the stated aims and objectives.

The type of evaluation that is required can be determined by preparing a list of questions (Table 2.7), which focuses on what the final information requirements are for the evaluation. These requirements are supposed to be established by the evaluation drivers and intended information uses – which have already been identified in sections 2.5.1 and 2.5.2 (Glenaffric Ltd 2007; NSW Government 2011d).

Table 2.7 shows that the purpose, extent, focus and timing of the evaluation match the description for an "appropriateness" evaluation. Having defined the critical elements of the evaluation, it is now possible to prepare a plan.

Table 2.7: Questions to help focus on the type of evaluation required
Template from (NSW Government 2011d)

Question	Consideration of drivers/needs
Purpose of evaluation: What is the purpose of the evaluation?	The purpose of the evaluation is to identify the appropriateness of using a UAS in a specific surveying application.
Extent of implementation: What stage of implementation has the proposal reached?	The "proposal" to purchase and use a UAS for survey work is still in the consideration stage, i.e. there has been no implementation. This means that the evaluation is performed before the evaluator/surveyors knows any precise details about the UAS and its capabilities.
Focus of evaluation: What aspect of the proposal/project is the evaluation focusing on?	The evaluation is focused on defining the benefits and disadvantages of using a UAS. Summarising the drivers and information uses, the evaluation is targeted at identifying: • The professional and legal requirements for using a UAS for commercial survey work; and,

	• the effects that using a UAS will have upon business efficiency and productivity; and, • the usability or ease-of-use of the UAS; and, • the accuracy that can be achieved with the UAS.
Timing of evaluation: At what stage during implementation is the evaluation to occur?	The evaluation is to provide knowledge about the appropriateness of using a UAS, i.e. what benefits it will provide and if these benefits outweigh the cost. It is therefore conducted before the UAS is acquired and before new operating procedures are implemented.

2.6 Planning an evaluation for appropriateness

Broadly speaking, evaluations of this type are concerned with identifying if there is a need for a particular procedure, program, system etc. (in this case, a UAS), or determining if the procedure or system can be used to meet specific objectives or outcomes (NSW Government 2011a). To achieve this, an evaluation plan needs to be laid out which will describe the objectives; how success or performance will be measured; and how data will be collected (Glenaffric Ltd 2007). Table 2.8 outlines the five elements of the evaluation plan that will be discussed in this section.

Table 2.8: Evaluation Plan Template

Objective	**Indicators**	**Source of Information**	**Collection Method**	**Other details**
Objective	How will success be measured?	Is there a source readily available?	How will the information be obtained?	Where, when and who will collect the information?

2.6.1 Objectives for the UAS

The first elements is the objectives, or outcomes, which define exactly what the evaluator is seeking to learn about the UAS, so that they may determine the need or appropriateness. Objectives must be (NSW Government 2011b):

- Relevant to the purpose of the evaluation.
- Achievable.
- There should be confidence in the validity of the information that can be gathered relating to the objective.

The discussions of evaluation context, scope, internal and external drivers and information uses have highlighted a number of key elements that the evaluation must focus on in order to fulfill its purpose. These are:

1. Legal obligations and restrictions
2. Professional expectations
3. Efficiency and productivity benefits gained from the UAS
4. What advantages the UAS has over other surveying methods
5. The limitations of UAS in surveying applications

Considering the purpose of the evaluation, and the above key elements, four objectives can be defined when considering the needs of the stakeholders:

1. Determine the legal requirements of the UAS operator with respect to the application and type of UAS.
2. Determine if the UAS can achieve the required accuracy.
3. Determine if the UAS is easier to use, or offers some significant non-technical advantage over alternative surveying methods.
4. Determine if the UAS can achieve an increase in productivity.

2.6.2 What are indicators?

The second element of the evaluation plan are the indicators, or performance measures. Indicators are what will used to measure how well the objectives have been met. These should be clearly defined—ambiguity will only compromise the quality and scope of the evaluation.

Indicators can be qualitative or quantitative; a mix of quantitative and qualitative information will enable a wide variety of information sources to be consulted and ensure a richer information base (NSW Government 2011b). Generally, accurate decisions regarding need or appropriateness cannot be based on a single information source or type. This is because, in some situations, the need for non-technical, qualitative characteristics such as ease-of-use may outweigh the need for technical, quantitative characteristics such as accuracy, i.e. when accuracy is not critical, and there is a lack of trained staff.

Therefore, the nature or type of data is not as crucial as ensuring that indicators are specific, measurable, achievable, relevant, and timely. These four terms form the "SMART" criteria (NSW Government 2011c), which have been used by other evaluation plans when defining indicators. The SMART criteria summarise the key qualities of good indicators, and can be organised into an assessment table (Table 2.9) for the quick and simple assessment of indicators.

Table 2.9: SMART Assessment	
Criteria	**Assessment**
Specific	
Related to intent?	
Linked to requirements?	
Measurable	
Readily available?	
Available data sufficient?	
Acquisition practical?	
Process repeatable?	
Achievable	
Cost effective?	
Realistic effort?	
Who will gather data?	
Who will analyse data?	
Relevant	
Relevant to project aims?	
Timely	
Data available when required?	

Specific

- Is the indicator related to the intent of the objective? I.e. will the information serve the purpose of the evaluation?
- Is the indicator directly linked to what is required for the evaluation or is it a surrogate? I.e. will it specifically inform the evaluator about the UAS performance in the relevant objective?

Measureable

- Is the data readily/already available? I.e. has literature been published which will provide the necessary information?
- Is the available data sufficient? I.e. will the existing literature be adequate for an accurate judgment/evaluation?
- Is gathering the data easy and practical? Either through research or physical measurements?
- Can the process for gathering the data be easily repeated? I.e. if an experiment/physical measurement is required, can it be reproduced?

Achievable

- Is the process for gathering data cost-effective? I.e. do the benefits truly outweigh the time, money and effort needed to gather the necessary personnel, equipment etc.?
- Is the effort realistic? I.e. does gathering and analyzing the data require a reasonable amount of resources or does it occupy several staff and computers for several days?
- Who will be responsible for gathering the data? Do they have the knowledge and skills necessary to carry out the task?
- Who will analyse the data? Again, do they have the appropriate knowledge and skills?

Relevant

- Is the information relevant to the aims of the evaluation as a whole? I.e. will the information only satisfy one small requirement or can it be used to feed other indicators?

Timely

- Will the data/information be available when it is required? This means, will the evaluation be available for analysis before the process moves onto the next stage? This is not necessarily applicable in this instance, because the process is under the complete control of the evaluator. However, if the information takes several weeks to gather and process, then it may not be appropriate to use as an indicator simply because the time frame is too large.

2.6.3 Indicators for legal responsibilities

The aim of this indicator is to identify the Spatial Scientists' legal responsibilities when using a UAS in their desired application, and to provide an estimate of the effort and cost associated with fulfilling those responsibilities. With this information a decision can be made about whether or not to pursue certification, and thus begin using a UAS.

Legal implications explained

In Australia, the control and regulation of unmanned aerial vehicles in Australia's controlled airspace is the responsibility of the Civil Aviation Safety Authority (CASA). The Civil Aviation Safety Regulations (CASRs) (described in section 2.9) require that anyone who intends to use a UAS for commercial purposes be adequately certified. They also specify some restrictions upon how they are to be used.

This includes limiting the operational range of the UAS to within a visible line of site, and preventing the UAS from being flown in certain areas. It is necessary that the surveyor understands these conditions, and is aware of their impact upon the use of a UAS for their desired application.

Assessing legal responsibilities

The CASRs apply to all of Australia (section 2.9). As described in section 2.9.6, the worst case scenario for the cost of an operator's certificate lies at approximately $7865-$10875 plus the cost of developing a manual of operations.

Table 2.10: Minimum CASR requirements for UAV operation

Category	Application requirement		CASR Condition	Outcome
Who will operate the UAV?	1. Does an employee of the organisation possess a Controller's Certificate?	Yes →	Proceed to the Operator's Certificate.	No cost for controller certificate.
		No →	An employee will be required to obtain a controller's certificate.	+ $865 to $2875 to the cost of certification (worst case).
	2. Does a manager in the organisation possess an Operator's Certificate?	Yes →	Anyone in the organisation with a Controller's Certificate can operate the UAV.	No cost for operator.
		No →	The manager/an employee will need to obtain an Operator's Certificate.	+ $7200-$8000 to cost of certification (worst case scenario).
Where will the UAV be operated?	1. In a populous area (i.e. a city, town, or other area with a high population density)?	Yes →	You will require a certificate of airworthiness from CASA.	Varies depending on the circumstances.
		No →	UAV can operate below 400ft above ground level, outside of prohibited and restricted airspace.	UAV can operate.

	2. In prohibited or restricted airspace, or near an aerodrome?	Yes →	You will need to contact the authority controlling the airspace and obtain a permit.	Wait for permit to be issued.
		No →	UAV can operate below 400ft above ground level, outside of prohibited and restricted airspace.	UAV can operate.
Under what conditions will the UAS be operated in?	Under meteorological conditions with good visibility (i.e. clear weather during the day), and within a visible line of site?	Yes →	UAV can operate below 400ft above ground level, outside of prohibited and restricted airspace.	UAV can operate.
		No →	You must complete an Instrument Rating exam (IREX) and obtain a permit.	Completing an instrument rating exam requires a Private Pilot License. To prepare for an exam, a training course can be completed which may cost up to $1,400.

The way that the UAS is going to be used impacts the certification process. There may be additional requirements if the surveyor intends to, for example, fly over populous areas or beyond a visual line of site. Table 2.10 is an assessment table which is intended to identify any additional requirements that apply to the surveyor's intended application.

This short assessment makes it clear to the evaluator what the organisation will be required to do in order to operate the UAS. The decision about whether or not the benefits of becoming certified outweigh the costs will then depend upon a number of factors including:

1. The results and information garnered by the rest of the evaluation, i.e. if the UAS is found to be significantly more efficient than the current practice, then the benefits could outweigh the costs.
2. If there are no other alternatives, i.e. the spatial scientist is contracted for work that no other survey equipment/method can complete (such as mapping hazardous areas), etc.

The assessment table provides the evaluator with an effective and repeatable way of understanding the legal responsibilities of their organization and the estimated cost of meeting those responsibilities. A brief SMART assessment shows that such an assessment table has many of the essential qualities of a good indicator (Appendix H). Therefore this can be considered an appropriate method for identifying legal responsibilities and the extent of the cost and effort involved.

2.6.4 Indicators for efficiency and productivity

The aim of this indicator is to identify if the UAS is capable of providing an increase in efficiency and productivity. “Efficiency” is included in this evaluation on the basis that the most significant impact a UAS can have on a business is an increase in productivity. Formally, the productivity or efficiency of a business is a subject that runs significantly deeper than the very simple explanation for efficiency provided below. However, business accounting is a subject that extends beyond the scope of this project. The concern of this evaluation is determining if the UAS can provide an increase in productivity. If the UAS can provide the desired output faster than the methods currently employed or available, then it will result in a more productive enterprise.

Efficiency of the UAS

A primary objective for any business is increasing efficiency. Efficiency is defined as:

> "*effective operation as measured by comparison of production cost with energy*" (Mirriam-Webster 2013).

An alternative definition is:

> "*performing or functioning in the best possible manner with the least wasted time and effort"* (Dictionary.com 2013).

From these definitions, it is clear that the state of being "efficient" is simply producing the desired result in the fastest possible manner at the lowest cost. However, the major concern for this project is, simply, if the UAS can operate *faster* and at a *lower* cost than the current process.

Efficiency as an indicator

A process is a sequence of linked activities or procedures consuming resources (i.e. inputs) and converting them into outputs (Business Dictionary 2013). Every job that a surveyor completes is essentially a process that consumes resources (such as time, personnel, etc.) and produces outputs (i.e. digital terrain models, asset maps, an updated title in the freehold land register, etc.). Therefore, as a process, the "efficiency" of a surveyor's work can be increased by:

- decreasing the inputs required to produce the same output; or
- decreasing the amount of time or energy required to turn inputs into outputs; or
- increasing the outputs in terms of quality or volume.

In surveying, the primary resources (inputs) are personnel (i.e. surveyors, chainmen), equipment (i.e. the UAS) and time. However, because the "equipment" (or its effect upon other indicators) is the subject of the evaluation, it will not make a suitable indicator itself.

The *personnel* and *time* requirements of surveying with a UAS can be used to identify increases or decreases in efficiency. However, in order for this to succeed, both "personnel" and "time" must be reduced to a common figure; in this case, a dollar figure. For this, it is assumed that the manager of the business will know the cost per hour of having personnel in the field. The base cost per hour could be used, or if necessary a more comprehensive value could be used which includes salary on-costs and overheads (USQ 2013).

The "time" requirement will be most accurately determined by performing a test run (or experiment) with the UAS. This will involve measuring the time taken to perform an entire survey, including fieldwork and office work, thus providing the evaluator with an estimate that is accurate for their intended application. While this increases the effort required to complete the evaluation, the data gathered during the experiment will be used for other areas of the evaluation (i.e. accuracy and usability).

With this information, the approximate cost of a particular survey can be calculated with:

$$Cost = (hours) \times (personnel) \times (cost\ per\ hour)$$

For example, if the cost of employing a surveyor was $100 per hour, and the:

- Inputs for conducting a survey with a UAS was:
  - 1 personnel
  - 20 hours including field and office work
- Inputs for the alternative method was:
  - 2 personnel and 5 hours for field work
  - 1 personnel and 8 hours for office work

Then the cost of each method could be calculated as:

$$Cost\ for\ UAV\ method = 1 * 15 * 100 = 1500$$

$$Cost\ for\ alternative\ method = (2 * 5 * 100) + (1 * 8 * 100) = 1800$$

In this example the UAS—although taking more time to produce an output—requires fewer personnel, so it can be considered more efficient than the alternative, and therefore fulfilling the objective of improving business efficiency and productivity.

Also note that in the above example the cost of employing the surveyor is a redundant component of the calculation. Simply multiplying the number of personnel by the hours of work performed would have provided a sufficient comparison.

However, the situation may arise where the surveyor needs to include additional costs (i.e. subcontractors), or different staff are needed who are on different pay grades. Then, it becomes important to use the actual cost of employment in order to make an accurate comparison.

For example, if a surveyor regularly produces topographic maps for a client using photos captured by a full sized aircraft outfitted for photogrammetric missions, then the cost of the subcontractor will need to be included. Then, if two staff members are required to process the data including one staff member on a high pay grade and one staff member on a low pay grade, then this must also be included in the calculation.

After performing the calculation below, the surveyor will have a dollar figure which can be easily compared to the cost of producing the same topographic maps with a UAS.

$$
\begin{aligned}
Cost = {} & (cost\ of\ subcontractor) \\
& + \big((junior\ staff) \times (cost\ of\ junior\ staff)\big) \\
& + \big((senior\ staff) \times (cost\ of\ senior\ staff)\big)
\end{aligned}
$$

A brief SMART assessment (Appendix H) identifies that this method for determining efficiency possesses the qualities of a good indicator, and would be suitable to use in this evaluation.

2.6.5 Accuracy

Measurement accuracy explained

Accuracy is defined as the closeness of a measurement to the true value, in contrast with precision which is the closeness of measurements to each other (UNSW 2006). Refer to Fig. 2.15, which shows how precise and accurate measurements differ. For most survey work, there is a level of accuracy and precision that must be achieved.

The precision and accuracy of a measurement can be determined by measuring its residual: the difference between the measured value and the true value. If a large number of measurements are taken and the residuals for each can be calculated, then the statistics of these residuals (i.e. mean and standard deviation) will more thoroughly describe the accuracy and precision.

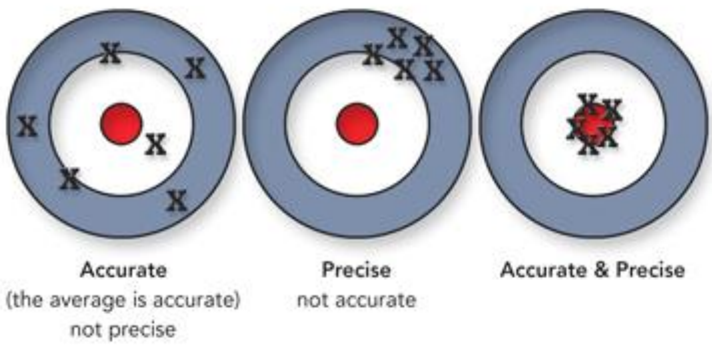


Figure 2.15: Precise and accurate measurements
Source: Forensic Talks

Many surveying instruments are accompanied with a confidence interval determined by the manufacturer, which describes accuracy and precision. For example, total stations are sold with a confidence interval for angle and EDM measurements (i.e. ±8” and ±0.01m). However, UAS systems are usually not accompanied with such a confidence interval.

This is because of the broad range of factors that come into play when determining the accuracy of the data gathered by a UAS (section 2.7). Many of these factors are variable, and depend on the planning and processing carried out to achieve the output. Instead of a confidence interval, many manufacturers provide specifications on those factors that affect accuracy, such as maximum photo resolution, minimum and maximum flying heights, flying speeds, and so forth.

To ensure that the UAS is truly fit for purpose, it will be necessary to determine the accuracy of the UAS using data acquired under normal working conditions. How this is carried out depends upon the intended application and the desired output.

The required accuracy and precision (i.e. if horizontal or vertical accuracy, or both should be analysed) and the way it is determined will differ depending on the required output, i.e. the method for determining the accuracy and quality of a DTM will differ to the method for determining the accuracy of a topographic map. However, the aim will be the same. That is, to determine the closeness of the measured values to the true value and express this closeness in terms of accuracy and precision.

In this project, a DTM will be created using photographs from a UAS, which will be used to determine stockpile volumes. Section 2.8 outlines the process for evaluating the quality and accuracy of a DTM.

A SMART assessment (appendix H) reveals that accuracy is not a "real" indicator, because the process for determining accuracy is not easily defined (it depends on the output/use); requires special effort; technical knowledge; and the experiment used to gather data may not be repeatable. However, understanding accuracy is a critical component for understanding how well the UAS will perform in the desired application, and so it must be included in the evaluation.

2.6.6 Indicators for usability

This sub-section will describe subjective usability and how it can be used as an indicator.

Subjective usability

Usability is a concept that is becoming more meaningful in the modern era, with the vast amount of complex technologies that are now available. This is because people need technology to achieve certain outcomes, but are not necessarily concerned with the internal workings of a system, and do not need to be bothered by its complexities.

This is especially true when using a UAV. To a surveyor, a UAV is simply a tool for acquiring spatial data. However, the UAV itself is much more than this. It is an automated flying machine comprised of complex electronics, sensors and software. As such, to be at all useful, these complexities need to be simplified by an interface that enables the surveyor to interact with the UAV in an intuitive and efficient manner. This is called usability.

Usability is regarded as a measure of the ease of use and the learnability (i.e. how easily it can be repeatedly used) of a particular piece of equipment or interface, when designed for a particular purpose (Nielsen Norman Group 2013). Ultimately usability is a subjective concept and therefore difficult to measure; however there have been efforts made to formalize a process for assessing it.

Subjective usability as an indicator

Due to the subjective nature of usability, these processes normally involve the use of some form of survey or questionnaire (Brooke 1986). One such survey that has been frequently utilized is the “System Usability Scale (SUS)” (Appendix B) developed by Digital Equipment Co Ltd (Brooke 1986), which is a 10-question survey designed to assess the usability of a system in any given context.

The SUS evaluation is based on a “Likert scale”, which is constructed by selecting opposing questions that test the respondent’s attitude towards a particular subject at two different extremes. This means that each question must be paired with another for the SUS scale to be accurate.

The SUS is suitable for this evaluation because:

- It is easy to apply.
- It reduces “usability” to a single numerical value that can be used to compare different evaluations.

The process is very basic. In this context, the person who uses the UAS will respond to each of the 10-questions using a rating system. The respondent uses a scale of 1 (strongly disagree) to 5 (strongly agree) to describe how much they agree with each question, as demonstrated in the example below:

Question 1: I think that I would use this system regularly…

Response to Question 1					
	Strongly Disagree				Strongly Agree
Use of UAS					**X**

Once the questionnaire is complete, the responses are scored and tallied. Even numbered questions (i.e. 2, 4, 6 etc.)—the “negative” questions—are scored by subtracting the respondent’s score (i.e. 1-5) from five. For odd numbered questions (i.e. 1, 3, 5 etc.), the SUS score is the respondent’s rating (i.e. 1-5), subtract 1. Using this scoring system makes it important that the questions are answered and scored in the correct order. See Appendix B for more details on how the SUS evaluation works.

A SMART assessment (Appendix H) shows that the SUS scale is a suitable tool for evaluating and comparing the usability of different survey methods including UAS.

2.6.7 Evaluation plan

The objectives and indicators described in the preceding section can be collated into an evaluation plan which can be used to guide the evaluation for this project. This plan is outlined in Table 2.11. This is intended to act as a tool for guiding the collection and analysis of information. By following this plan the advantages, disadvantages and overall benefits of using a particular model of UAS for coal stockpile surveys should be identified.

Table 2.11: Evaluation Plan

Objective	Indicators	Source of Information	Collection Method	Other details
Determine the legal requirements of the UAS operator with respect to the application and type of UAS.	Legal requirements as described in the assessment table in section 2.6.3.	Review of section 101 of CASRs, circular advisories, and an evaluation using the assessment table.	Research and review of legislation (ensure that the legislation has not been superseded first)	Evaluator to determine requirements of the intended application and make a comparison using assessment table, to determine legal requirements.
Determine if the UAS can achieve an increase in productivity.	Cost of work performed as described in section 2.6.4.	Personnel requirements determined by experiment design; time requirements measured	Maintain time logs throughout experimentati on period, which will be used to evaluate the	If the evaluator does not perform the experiment then a subordinate must be instructed to

		during experimentation	performance of the UAS and alternative methods.	maintain time logs during the experiment.
Determine if the UAS can achieve the required accuracy.	For coal stockpile survey: the quality of input data (point density, measurement quality) and statistical analysis (standard deviation, mean, etc.) of external quality of DTM including residual plotting, and a comparison of the volumes.	The analysis will be performed using survey data acquired from the experiment, and analysed using various visual and statistical tools.	Data is collected and processed according to predetermined methodology. The quality of the input data and the external quality of the DTM is then analysed using the appropriate approach (section 2.8)	The evaluator is to design an experiment that meets their particular needs (i.e. a field survey using the UAS). The evaluator then analyses the results to check data quality and ensure the results meet the specified job requirements.
Determine if the UAS is easier to use, or offers some significant non-technical advantage over alternative surveying methods.	Usability (SUS) assessment.	Results are obtained from an SUS evaluation during the operation of the UAS.	The System Usability Scale evaluation plan described in Appendix B.	Evaluator or subordinate must perform the evaluation while UAV is in use.

2.7 Factors influencing the accuracy of photogrammetry

The aim of this section is two-fold; first it is to demonstrate to the reader the wide range of factors that impact the accuracy of photogrammetry. Second, it is to review those factors and discuss how they should be considered during a flight with the eBee and other UAVs.

2.7.1 Photo resolution

Photo resolution has been mentioned in a preceding section (2.4.2). A higher photo resolution will provide more accurate results, because features are able to be more easily distinguished (Fig. 2.16) (Eos Systems Inc. 2013). There are two ways to achieve higher ground resolution: use a camera with more megapixels or fly closer to the ground.

Figure 2.16: Greater resolution improves image quality. However there is a point where more pixels will no longer provide any meaningful benefits.

If the photo resolution is 3.8cm per pixel (photo resolution of eBee's camera at 400ft AGL), then this will theoretically be the maximum resolution of a DTM produced with those photographs (that is, 3.8cm spacing for points). Although, generating a DTM at this resolution is often impractical and unnecessary. In fact, extremely dense point clouds will often have lower surface quality than those with a more reasonable point spacing such as 1m (Walker & Willgoose 2006).

2.7.2 Camera calibration

Camera calibration is the process of determining camera characteristics such as focal length and image dimensions. In order to obtain high-accuracy results, it is important that these parameters are known and inserted into the software so that the photos can be correctly matched and scaled, and so measurements can be made (USQ 2012). For the eBee UAV, the camera calibrations are known and pre-inserted into the software (Fig. 2.17).

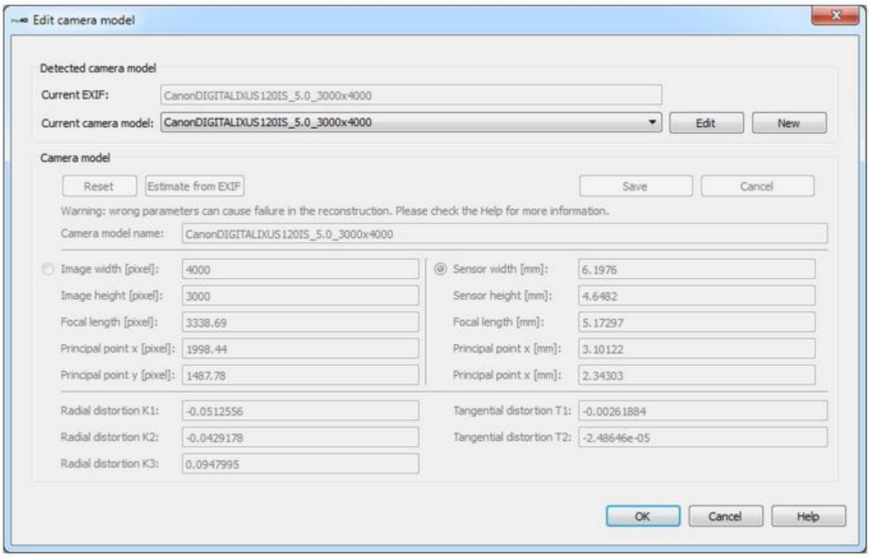


Figure 2.17: Camera calibrations in Postflight Terra 3D Software

Photo-processing without correctly entering the camera calibration can be likened to a surveyor attempting to measure a distance with an EDM and a prism, without knowing the correct prism constant.

2.7.3 Angles between photos

Overlap affects the "angle between photos". Smaller overlap (i.e. less than 60%) means the images are recorded further apart, which increases the angles between the photographs (Eos Systems Inc. 2013) (Fig. 2.18). Greater overlap (i.e. greater than 70%) means the images are recorded closer together, thus resulting in smaller angles between photographs. Neither large angles nor small angles are preferred, with either extreme resulting in less accurate parallax measurements.

For aerial photogrammetry there is an optimum level of relief displacement that should be considered. Ideally, the overlap should be fixed to 55-65% (i.e. roughly the level of overlap present in human binocular vision) to provide the best possible results (Henson 1993; USQ 2012).

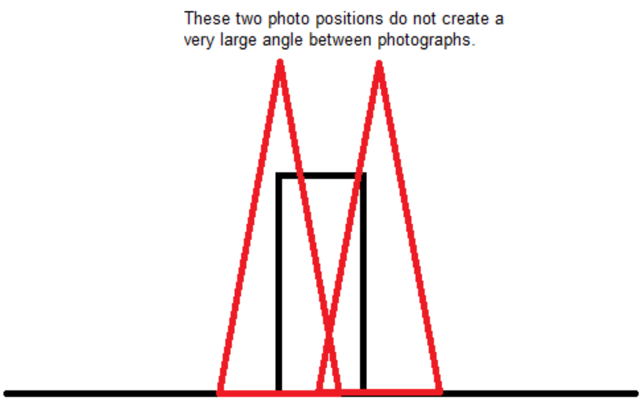


Figure 2.18: Relying on photos that are taken close together will not provide good results, because this provides only a limited level of relief displacement.

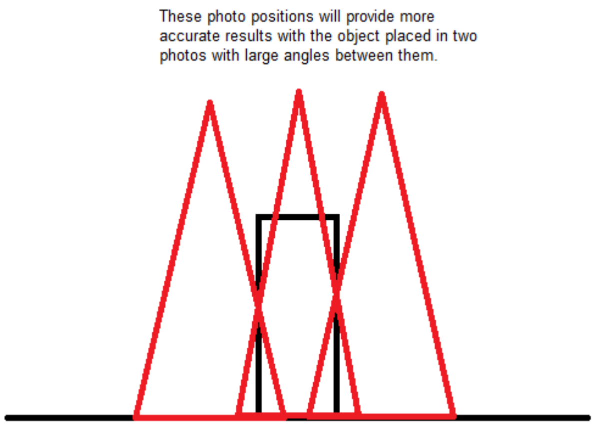


Figure 2.19: Capturing photos at the optimum overlap will ensure a good angle between photographs.

2.7.4 Photo redundancy

If a control point or feature is located on a large number of photographs, then it will be modeled more accurately. This is because the photoprocessing software will have more common points between each photograph to optimize photo positions. As such it is good practice to record more photographs than what is minimally required; this is called photo redundancy.

But while recording more photographs will increase the number of redundancies and theoretically increase the accuracy of the model (Eos Systems Inc. 2013), there is the angle between photographs to be considered (section 2.7.3). It is recommended that photo redundancy is pursued, and if a photo is deemed unnecessary then it can be excluded from processing at a later stage.

2.7.5 Ground control points

Ground control points are features or targets which are easily identifiable in the photographs, and have been accurately surveyed. They can be natural or pre-existing (i.e. concrete slaps, tree stumps, etc.), or man-made (i.e. manufactured for the purpose of an aerial survey). Accurately and easily distinguishable ground control points (GCPs) are crucial for (USQ 2012):

1. Image Georectification
2. Image scaling
3. Aerotriangulation

Considering the low flying height of the eBee and the high resolution of the camera it is not necessary for ground control targets to be excessively large. If the targets are oversized then processing accuracy will be decreased because the centre of the target becomes more difficult to identify correctly. Therefore small, but easily identifiable GCPs should be selected.

2.8 Quality assessment of DTMs

The accuracy and precision of digital terrain models (DTMs) are not parameters that can be defined generally. Not only because accuracy and precision can be considered in a number of dimensions (i.e. horizontal and vertical), but because DTMs are not "elementary data". That is, DTMs are actually derived using primitives such as 3D points and lines, which will themselves have their own accuracy and precision.

As such, the quality and accuracy of the DTM can only be determined by analyzing it on two distinct levels. The first level is the quality of the input data, that is; the quality of the data used to generate the DTM. The quality of the input data is determined, among other things, by the distribution of points and the accuracy of the direct measurements (Karel, Pfeifer & Briese 2006).

The second level is the exterior quality. This is determined primarily by using external data that is of higher accuracy, which was not included in the generation of the DTM. This might include a list of check-points, or a second DTM generated through a different method. The differences (i.e. residuals) between the DTM and the check data can be evaluated to determine accuracy and precision (mean and standard deviation) (Karel, Pfeifer & Briese 2006).

2.8.1 Quality of input data

The exterior quality of a DTM is dependent on the accuracy of the input data, and will therefore be indicative of the accuracy of the input data. However, looking at the input data is still necessary because methods of assessing the external quality do not account for the surface quality of the DTM. The "surface quality" describes a number of factors that may have a significant impact on residuals, such as shadow and point density; surface complexity; and measurement quality (Karel, Pfeifer & Briese 2006). As such, before comparing the DTM with external check data it is important to take note of shadow areas and the density of the point cloud.

Measurement quality is confirmed by preprocessing results when preparing the data for use. How measurement quality is reported varies depending on the nature of the input data. For example, the measurement quality of a terrestrial laser scanner is presupposed by the manufacturer's confidence interval (for point measurements), and analysed post-survey by the results of a multi-station adjustment. However, the measurement quality when processing photographs is analysed post-survey by using a number of indicators including the adjusted internal camera parameters and the residuals between the adjusted photo-positions and the measured positions of the ground control points. As such, when comparing two different instruments for accuracy it is difficult to use these post-processing results for such a comparison. They are only useful for confirming the quality of each dataset.

2.8.2 External quality

As mentioned earlier the external quality of a DTM is assessed by determining its relationship with the actual terrain being modeled. This is achieved through the use of external check (or "ground truth") data. The variations between the UAV DTM and the check data are analysed visually and statistically, to determine if these differences are the result of systematic, random or gross error. Jancso and Melykuti (2011) used the following statistics in their comparison of DTMs:

- Minimum and maximum residual
- Range of the residuals
- Mean of the residuals
- Median residual
- Standard deviation
- Standard error

The type of data that is used to check the external quality depends on how the DTM was generated; the desired accuracy; and on what is available. Sources of check data may consist of GPS or total station points stored on the terrain surface; a second DTM generated through an alternative method of which the accuracy is known and reliable (Jancso & Melykuti 2011), or another source of data of which the quality and accuracy is known.

2.9 The regulation and control of UAVs in Australia: CASR 1998

In this section the administrative body regulating the use of UAVs is introduced, along with the accompanying legislation. The main components of this legislation affecting the use of UAVs are outlined, and their impact upon the professional use of UAVs is discussed.

2.9.1 Civil Aviation Safety Regulations

The Civil Aviation Safety Authority (CASA) is the regulatory body governing the use of UAS in Australia, as designated by the *Civil Aviation Regulations 1988* (Cwlth), commonly abbreviated as CAR. The most significant regulation under CAR are the *Civil Aviation Safety Regulations 1998,* commonly abbreviated as CASRs, which is the document providing for the regulation and control of the use of UAS.

Part 101 (Unmanned Aircraft and Rockets) is the section of the CASRs that deals with unmanned aerial vehicles. In the case of UAS used for non-recreational (i.e. commercial) purposes, the parts applicable are:

- In Subpart 101.A Preliminary
    - 101.030 Approval of areas for operation of unmanned aircraft or rockets
    - 101.035 Requirements in this Part to give information to CASA
- In Subpart 101.B General prohibition on unsafe operation
    - 101.055 Hazardous operation prohibited
- In Subpart 101.C Provisions applicable to unmanned aircraft generally

    - 101.065 Operation in prohibited or restricted area
    - 101.070 Operation in controlled airspace
    - 101.075 Operation near aerodromes
    - 101.080 Permission for operation of unmanned aircraft near aerodrome
    - 101.085 Maximum operating height
    - 101.095 Weather and day limitations
- In Subpart 101.F UAVs
    - All of this subpart

2.9.2 Subpart 101.A Preliminary

Section 101.030 outlines the powers of CASA with regards to approving the use of a UAS in a particular area. Importantly, this section also informs readers of the different classes of unmanned aircraft that CASA recognises. It distinguishes UAVs from other classes of unmanned aircraft by defining them as:

- Unmanned aircraft other than a balloon or a kite.
- A model aircraft, which is considered to be anything flown only for sport and recreation (as a pose to commercial use).
- UAS/UAV which are unmanned aircraft flown for commercial purposes.

Additionally, section 101.035 explains how to give information to CASA about a person's use of a UAS. It also explains that CASA may request further information if it relates to the use of a UAS.

2.9.3 Subpart 101.B General prohibition on unsafe operation

Section 101.055 outlines the duty of an operator to guard against the unsafe or hazardous operation of a UAS, and describes the penalties if the operator fails in this duty. Essentially, the operator must not operate the UAS in a way that creates a hazard to other aircraft, people or property.

Importantly, this section explains that just because the UAS was launched and operated in a manner that complies with an operation manual (including those issued either by CASA or the manufacturer), it is not automatically considered 'safe'. The operation is only safe if it does not endanger people, aircraft or property. This ensures that the responsibility for safety remains solely with the operator.

2.9.4 Subpart 101.C Provisions applicable to unmanned aircraft generally

This section describes where a UAS can be operated in general. A UAS cannot be operated in a prohibited or restricted area unless authorized by the authority controlling that airspace (101.065). However, it is safe to operate a UAS in controlled airspace (i.e. Australian airspace) as long as it remains below 400 feet above ground level (AGL). Otherwise, authorization is required (101.070). Operation near an aerodrome is also restricted and requires authorization (101.075).

Evidently the maximum flying height without special permission is 400 feet AGL (101.085). Furthermore, a UAS cannot be operated in non-visible conditions (i.e. foggy or at night) unless they hold the necessary certifications (101.095). It is also prohibited to drop/discharge objects from a UAS while it is in operation unless it can be verified that it will not damage/harm anyone or thing (101.090).

These regulations will not have an immense impact upon the use of a UAS in survey work, unless the surveyor intends to operate in a prohibited or restricted area, near an aerodrome or above the maximum flying height. However, the restriction upon visible conditions (i.e. can only be operated on clear days, and not at night) may prove to be limiting, especially in localities that experience these foggy or otherwise non-visible conditions regularly (i.e. mountainous regions).

2.9.5 Subpart 101.F UAVs

Which UAVs do these regulations apply to?

Section 101.240 designates three classes of UAV, those being:

1. Large UAV, which can be a:
   a. Unmanned airship with a capacity greater than 100 cubic metres
   b. Unmanned powered parachute with a launch mass greater than 150 kilograms
   c. Unmanned aeroplane with a launch mass greater than 150 kilograms
   d. Unmanned rotorcraft (such as a helicopter) with a launch mass greater than 100 kilograms
   e. Unmanned powered lift device (aircraft with flaps, slats etc. intended to increase lift) with a launch mass greater than 100 kilograms
2. Micro UAV with a gross weight of 100 grams or less
3. Small UAV, which is any UAV that isn't a micro or large UAV

The CASRs do not apply to all of these classes. Section 101.235 deals with the applicability of Subpart 101.F and clearly states that micro

UAVs are exempt, as are small UAVs if they are only being used for recreational purposes *and* the UAV is kept in sight at all times. However, this does not exclude any unmanned aerial vehicle used for commercial purposes, and therefore surveyors will need to consider these regulations before using a UAS for survey work.

According to section 101.255, large UAS are only permitted to be flown with airworthiness and experimental certificates, indicating that they are an experimental class and generally not allowed for commercial or professional use. For the remainder of this section, the focus will be upon *small UAVs*.

Where can UAVs be operated?

Sections 101.245 and 101.250 describe where it is acceptable for small UAVs to be used. It is not permissible to:

- operate the UAV within 30 metres of a person not associated with the UAV's operation; or
- operate the UAV outside of an approved area.

An approved area is only designated when special permission is necessary, i.e. in the case of restricted airspace or near an aerodrome. Specific approval is not necessary if the UAV flies below 400 feet above ground level (AGL), operates outside of prohibited or restricted airspace, and is not near a populous area.

For populous areas, section 101.820 applies. A populous area is regarded as an area with a high population density, where the event of a malfunction causing the UAV to lose altitude would create unreasonable risk to people and property. This is not simply an urban area; it means an area where there is a high density of people. For example, a camp site may be regarded as a populous area when it is full of people who are camping. However, when all of the campers leave it is no longer a populous area.

To avoid unreasonable risk, CASA requires that all UAVs which are going to be operating near a populous area have a certificate of airworthiness. Regulation 101.280 explains that a UAV may not be operated over a populous area unless it is certified, and any UAV that is certified must not operate below a height that would cause unacceptable risk unless the operator has approval from CASA.

Simplified, a UAV can be operated anywhere outside of a prohibited or restricted airspace, providing it remains below 400 feet AGL, and it is not near any populous areas. Otherwise, the operator requires approval from CASA. For most rural and mine site surveying, these conditions can be easily met and there is no requirement to contact CASA for approval.

Who can operate UAVs?

Just as importantly as where the UAV can be operated, is who can operate it. Regulation 101.270 states that if an individual intends to operate a UAV for reward (which is the case of most professionals), then they must have a UAV operator's certificate.

To obtain an operator's certificate you must first possess a "controller's certificate". The certification of UAV controllers is dealt with in Division 101.F.3. However, this is just one step in the lengthy process of obtaining an operator's certificate. The process is outlined more clearly on CASA's (CASA 2013b) website. When applying for a certificate, CASA recommends:

1. *Develop a business plan, concept of operations and safety case*

   Section 101.330 of CASR requires applicants to provide details on their organization, including information about how the UAV will be used, staff qualifications, practice, procedures and details of available facilities. Not only is this information required for the application, but by completing this step thoroughly, the organization will have a well-developed road map for future business using the UAV.

2. *Determine the aircraft you wish to operate*

   Much of the information you are required to provide for your application depends upon the type of aircraft you are going to operate, specifically if the UAV is fixed wing or rotary, and if it is a micro, small or large UAV.

3. *Undertake the relevant pilot exams*

   Under section 101.295, an applicant must be awarded a pass in the relevant exams before receiving a UAV controller's certificate. The relevant exams include the UAV Pilot's License exam, the radio operator's certificate of proficiency and the instrument rating exam.

4. *Obtain a Class 2 medical certificate (optional)*

   The CASA website explains that applicants should acquire an aviation medical certificate before proceeding. This is not a regulatory requirement, and is purely a recommendation from CASA.

5. *Obtain a UAV controller certificate*

   Obtaining a UAV controller certificate is a significant step in the process. Section 101.295 describes the eligibility requirements for a controller's certificate, and these include:

   i. Applicant qualifies for a radio operator's certificate of proficiency.
   ii. Has passed the relevant aviation theory examination
   iii. Has passed the instrument rating theory examination
   iv. Has completed the training course relevant to the type of UAV to be operated, conducted by the manufacturer

v. Has at least 5 hours experience operating a UAV outside of controlled airspace

Note that the CASRs adopt a legal fiction whereby the purchaser of a UAV becomes the "manufacturer". Therefore, the person or operator who owns the UAV can provide the training course required to obtain the operator's certificate.

6. *Apply for an Instrument Rating Exam exemption*

If the UAV is not going to be operated outside of "Visual Line of Sight" (VLOS), and will only be operated during "day Visual Meteorological Conditions" (VMC), then the applicant may apply for an exemption from the instrument rating exam.

However, this is more of a requirement than a recommendation when the pre-requisites for the instrument rating exam are considered. As a minimum for UAV certification, all applicants must complete the "Private Pilots License (PPL) *theory exam*". However, in order to eligible for the instrument rating exam, it is not enough to have simply passed the PPL exam. The applicant must possess an actual Private Pilots *License* (CASA 2013d), which involves a significant amount of training that extends well beyond the normal requirements of UAV certification.

This requirement means that sitting an instrument rating exam is far out of reach for many surveyors who are operating their own business. This will limit the range of the UAS to that of a visual line of site.

7. *Assess the risk of your planned operations*

It is recommended by CASA that the organization attempts a risk assessment before proceeding with UAV operations.

8. *Develop a Safety Management System (SMS)*

It is not a regulatory requirement to construct a SMS in order to acquire an operator's certificate. However, many businesses already have an SMS in place which covers normal business activities. If a UAV is included into the business' list of services, then the SMS will need to be modified.

9. *Prepare your flight, operations and maintenance manuals*

   This is the responsibility of the "chief UAV controller". That is, to prepare standard operating procedures for the operation and maintenance of UAV equipment.

10. *Check your public liability insurance*

11. *Organise a pre-application interview*

    This is the final stage in the process, where the applicant is interviewed by a CASA official to ensure their application is in complete order before submission. The cost of this approval process varies depending on the travel and processing costs incurred by CASA officials. CASA have listed a worst case scenario of $7200 - $8000.

    How long the process lasts depends a lot on the individual effort placed into study and the development of operational manuals. Acquiring an operator's certificate can take several months to a several years to complete depending on the individual.

When the operator's certificate has been approved, it carries the condition that the operator appoints a "chief UAV controller" within their organization. The responsibility of the UAV chief controller is to control the training of UAV controllers, and to ensure the safe operation of the UAVs (CASA 2002). At the end of this process, the organizational structure of the business using UAVs will resemble that described in Fig. 2.20.

Evidently there is significant amount of training that is required in order to get staff certified. This will require a significant time investment, with aviation theory exams requiring significant amounts of study, and of course there are the associated costs to consider.

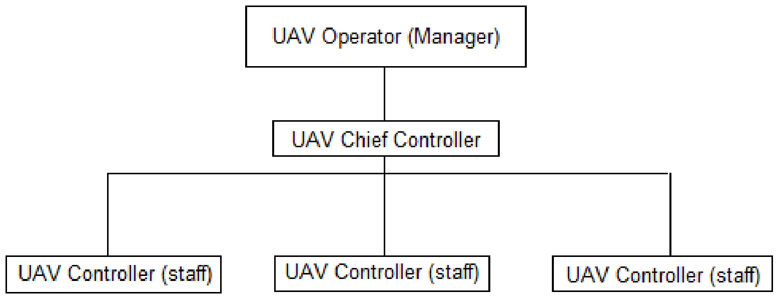


Figure 2.20: Organisational structure for a business using UAV/UAS

2.9.6 Breakdown of certification process

The process of obtaining a controller's certificate is, as described, sometimes lengthy and costly. The following table (Table 2.12) attempts to break down the process for controller certification, and gives cost and time estimates for each. Note that in Table 2.12 the cost of training, course materials and exams, and training times were gathered from a variety of information sources (UAVSMS 2013), (CASA 2013b) and (Tait 2013).

Once the controller's certificate has been completed, the following will need to be completed for the Operator's Certificate, as explained in the previous section (UAVSMS 2013):

1. Develop a Business Plan
2. Determine aircraft/UAV/Drone to use
3. Conduct Risk Assessment

Table 2.12: UAV Controller Certificate Cost Breakdown

Step	**Description**	**Prerequisite**	**Cost**	**Estimated time for completion**
1	Obtain ARN Number.	Nil	Nil	
2 (or 2a)	Purchase study materials and self-study for PPL theory exams	Step 1	Approximately $350 for new text books and learning materials.	Depends upon student; several months to several years.
2a (or 2)	Complete PPL theory training course	Step 1	Ranging from $650-$1200	1 week
3	Obtain "Aircraft Radio Operator Certificate of Proficiency"	Step 1	50$ to sit exam	A full day course for training, and several hours to sit exam.
4 (or 4a)	Apply for BAK exam and IREX exemption letters	Nil	Nil	
4a (or 4)	Complete Instrument Rating Examination training and exam (IREX)	Private Pilot License	$65 to site exam, approx. $1420 for training course. Must also consider additional requirements of the private pilot's license.	2 weeks for the IREX training course; must also consider the time involved with obtaining a full private pilot's license.
5	Complete PPL exam	Step 2	$65 to sit exam	1 Day
6	Class 2 medical certificate	Optional	$75 processing fee	4 weeks max for processing.
7	UAV manufacturers' course	Can be done in-house, supervised by the "manufacturer" (i.e. UAS reseller or the principle purchaser).		
8	Log 5 hours of experience	Can be done in-house, supervised by the "manufacturer" (i.e. UAS reseller or the principle purchaser).		
9	Submit application	Final Step	$160	Varies depending on complexity of application. Standard estimate at six weeks.
		Totals	Approx $865-$2875	

4. Write Operations Manual containing:
    a. Volume 1 – Policy and Procedures
    b. Volume 2 – Aircraft operations
    c. Volume 3 – Aerodromes and Routes
    d. Volume 4 – Training and Checking Organisations
5. Confirm Public Liability Insurance
6. Pre-Application Interview and
7. Submit UAV OC application.

CASA must completely assess the application before appointing an Operator's Certificate. In a worst case scenario the cost of this approval process may potentially range from $7200 to $8000, depending on the complexity of the application (CASA 2013b) and the applicant's distance from a CASA office.

As such, an approximate estimate for the cost of certification (controller and operator certificates) as a UAS operator lies between $7865 and $10875 as a worst case scenario. But, this does not include the cost of developing the "operations manuals" which can be done in-house, or with the help of contracting organizations, and may therefore vary significantly depending on the organization. After receiving an Operator's Certificate, there is an annual fee of renewal of $480.

Following this, the cost of certifying additional employees as UAV controllers can range from $865-$2875. The real costs may vary significantly depending on the method of study, special requirements, travel requirements for CASA officials and the complexity of the application. The time it takes to complete and process the Controller's Certificate and Operator's Certificate applications can also vary significantly depending on their complexity, the method of study and the completeness of the applications upon submission.

The significance of these costs depends on the circumstances of the organization. In some instances it may seem insignificant considering the cost of the UAS itself, which can exceed $50,000-$60,000 in most cases once software is included. For a large organization with many resources (i.e. a mining company), the cost and time involved with acquiring certification may seem like a general inconvenience, but relatively not of great significance.

However, for a general surveying consultancy with limited time and resources these conditions will be more difficult to meet. Managers may have difficulty finding the time to commit themselves and their staff to the training and certification process, which places UAS just out of their reach.

2.10 Related projects and studies

There has been research carried out prior to this paper, which is either very similar or related to the topics studied under this project. This section aims to summarise those related works, with additional commentary explaining how it is related to, and how it will impact this project.

2.10.1 Comparison of photogrammetry and survey laser scanning

In autumn 2012, Alison McQuillan conducted a terrestrial photogrammetric survey of a highwall at Anglo American's Foxleigh open cut mine, followed by a second survey with a terrestrial laser scanner approximately one month later. The aim of this study was to assess which was the more accurate of the two resulting datasets, and which method was more suitable for a joint and dip strike analysis of an open cut highwall. The findings were presented the following year at the 13th Coal Operator's Conference (McQuillan 2013).

McQuillan's study compared the two methods of data acquisition and processing in terms of time efficiency, physical effort and safety. However the work presented in this project is largely focused on aerial photogrammetry, so a comparison of terrestrial processes is largely irrelevant. But there are a number of useful observations that McQuillan makes about the use of terrestrial laser scanners, which are listed below:

- An assessment of the job site should be made prior to the survey, to select the most appropriate setup locations. Ideal setup locations should:
  - avoid data 'shadows' (areas in which there are no observations made); and,
  - be close enough to materials of low reflectivity to ensure adequate return signal; and,
  - be close enough to the area of interest to ensure adequate data resolution.

- To orientate the scanner, the scanner position is recorded through the use of RTK GPS, with a receiver mounted on top of the laser scanner. The backsight is recorded in a similar fashion, with a reflector positioned a suitable distance from the scanner with a receiver mounted above it. Although the method of orientation may vary between laser scanning products, it is useful to know that this method of orientation is used successfully by other surveyors and researchers.

McQuillan's comparisons between data handling and processing techniques, and the resulting datasets, are also relevant. One point of discussion was the ability to review the validity and completeness of data in the field. The laser scanner, operated through a laptop, provided continuous updates on the scan progress. Once the scan was complete, the data could be observed graphically and analyzed for shadows and other errors before moving on to the next scan position. If errors were found, the operator only needed to change the settings (if required) and re-run the scan. Terrestrial or aerial photogrammetry does not offer this functionality. The data must be downloaded at the office where photographs can be closely analysed and extensive processing must take place before the quality of the results can be known.

Once the processing was complete, it was discovered that the resulting two datasets differed significantly in accuracy. In many locations along the highwall, the datasets varied by up to one metre. McQuillan also observed that the digital elevation model (DEM) generated from the laser scanner was far more detailed than that of the photogrammetric process.

McQuillan concluded the study by stating that the laser scanner offered more reliable, detailed and accurate data compared to photogrammetry methods. These findings prompt some significant questions for this project. If terrestrial photogrammetry performs so poorly against a laser scanner, how likely is it that aerial photography will perform any better? Especially considering aerial photographs are taken from a much farther distance and usually (especially in the case of a small UAV) from a much less stable platform.

2.10.2 Evaluating the use of UAVs in Strip Mining

The study carried by Kiernan Smithson (Smithson 2010) in 2010 is very similar to this project. Smithson surveyed the stockpiling area at Ensham Coal Mine in Queensland using a small UAV as well as a terrestrial laser scanner, and then compared both the efficiency and accuracy of the two processes. However, there are several important differences between Smithson's work and this project:

- Smithson used a rotary wing UAV (i.e helicopter), as a pose to the fixed-wing model used for this project.
- Smithson's work was carried out in consideration of a single application (stockpile surveys), but this project aims to relate the results to other areas as well.
- Smithson's project took place three years ago; there has been a significant change to the UAV market since this time.

After an analysis of the technical (equipment, software, accuracy), economic, legal and operational factors, Smithson found that UAVs can be viable for use in strip mining. However, the laser scanner Smithson used performed better than the UAV in terms of speed and accuracy. Combining this with the cost of the rotary UAV, Smithson stated that its feasibility was limited for some applications. However, Smithson's concluding remarks state that as the market evolves, contracting "UAV surveyors" may become common and will cater for specialist jobs.

2.11 Summary

This chapter has provided background on a number of important topics for this project. It has defined the UAS, its history and the current level of UAS technology that is available. The variety of applications that UAS may be used for have been briefly described, and the current country and professional outlook pertaining to the commercial use of UAS within Australia has been identified.

The eBee has been described, and the process of planning a flight plan has been outlined, showing that the procedure is relatively simple and easy to perform. The most significant considerations when planning a flight with the eBee were shown to be flying height, and forward and lateral photographic overlap.

The need for an evaluation plan has been outlined, with the reasons for performing an evaluation being a combination of external (CASR regulations) and internal (professional responsibilities, business needs) drivers. The main elements of an evaluation plan have been described, and the evaluation indicators have been defined.

The factors influencing the accuracy of photogrammetry have been briefly outlined to provide background and justification for the specific parameters used for the flight plan and the method of analyzing accuracy described in later chapters.

The regulations for the commercial use of UAS have been described and an attempt has been made to estimate the cost of certification. The amount of time and effort required to complete training and certification has also been placed into context.

CHAPTER 3

Method

3.1 Introduction

This section outlines the methods used to collect the data required for the evaluation. The preliminary details are outlined, describing the conditions under which the experiment takes place and the basic design. This is followed by a detailed description of the methods used to collect and process the data.

3.2 Evaluation plan

The experiment is designed, and results will be analysed in accordance with the purpose and scope of the evaluation plan (sections 2.6), which is described in Table 3.1.

Table 3.1: Evaluation Plan

Objective	Indicators	Source of Information	Collection Method	Other details
Determine the legal requirements of the UAS operator with respect to the application and type of UAS.	Legal requirements as described in the assessment table in section 2.6.3.	Review of section 101 of CASRs, circular advisories, and an evaluation using the assessment table.	Research and review of legislation (ensure that the legislation has not been superseded first)	Evaluator to determine requirements of the intended application and make a comparison using assessment table, to determine legal requirements.

Determine if the UAS can achieve an increase in productivity.	Cost of work performed as described in section 2.6.4.	Personnel requirements determined by experiment design; time requirements measured during experimentation.	Maintain time logs throughout experimentation period, which will be used to evaluate the performance of the UAS and alternative methods.	If the evaluator does not perform the experiment then a subordinate must be instructed to maintain time logs during the experiment.
Determine if the UAS can achieve the required accuracy.	For coal stockpile survey: the quality of input data (point density, measurement quality) and statistical analysis (standard deviation, mean, etc.) of external quality of DTM including residual plotting, and a comparison of the volumes.	The analysis will be performed using survey data acquired from the experiment, and analysed using various visual and statistical tools.	Data is collected and processed according to predetermined methodology. The quality of the input data and the external quality of the DTM is then analysed using the appropriate approach (section 2.8)	The evaluator is to design an experiment that meets their particular needs (i.e. a field survey using the UAS). The evaluator then analyses the results to check data quality and ensure the results meet the specified job requirements.
Determine if the UAS is easier to use, or offers some significant non-technical advantage over alternative surveying methods.	Usability (SUS) assessment.	Results are obtained from an SUS evaluation during the operation of the UAS.	The System Usability Scale evaluation plan described in Appendix B.	Evaluator or subordinate must perform the evaluation while UAV is in use.

3.3 Preliminary details

3.3.1 Defining baselines

Before the evaluation begins, the preliminary details should be described. The purpose of this is to set the context for the rest of this chapter. The baselines should also be described. The baselines set goals for the evaluation and describe the minimum level of performance the UAS should achieve.

In this project the application being considered is the survey of coal stockpiles (calculating volumes). The UAS that is being evaluated is the eBee UAV. The eBee will be compared against a Terrestrial Laser Scanner (TLS), which will be used to gather external check data for the analysis of the external quality of the UAS digital terrain model (DTM).

The following points summarise the preliminary details and baselines of the evaluation:

1. When using a UAS in place of other survey methods, an important objective is increasing efficiency. As the TLS is the currently used method of surveying stockpiles and mine workings, the eBee should at least perform at the same level of efficiency as the TLS.
2. When evaluating legal responsibilities, it must be considered that:
    a. The mine site is not considered a populous area.
    b. The size of the stockpile area does not exceed a visual line of site.
3. When considering accuracy, the DTM should be of sufficient vertical accuracy, precision and quality in order to calculate an accurate coal volume. In a mining situation, when

comparing two volumes a difference of less than 2% is deemed acceptable.

3.3.2 Experiment design

For this evaluation a coal mine in the Central Highlands (Jellinbah Resources) approved a trial of the UAS during a survey of its coal stockpile area. Performing a trial of the UAS on a working job site provides the following advantages:

1. The experiment will be performed under the exact same conditions that will be experienced during normal use in the field (i.e. normal working conditions).
2. The capabilities of the UAS will be tested. A coal stockpile and its surrounding area contain a number of features which challenge the photogrammetric process, including sharp and subtle changes in elevation, with limited contrast between features (i.e. mostly black surfaces).

However, if a separate survey with the TLS is to provide check data for the UAS DTM, then the following considerations must be made:

1. It does not matter what order the surveys are performed in, but they must both include the same stockpiles. This means ensuring the stockpile area is available for the full amount of time required.
2. The stockpiles cannot be altered during the course of the survey; otherwise the two DTMs will be incomparable.
3. And additionally, health and safety requirements of the mine site must be met at all times.

Taking this into account, the experiment is designed as follows:

1. Arrive at the mine site and follow sign-in procedures. Make site liaison aware of arrival.
2. Ensure health and safety requirements have been met. This includes ensuring that all participants have read and agreed to the risk analysis and are aware of safety procedures.
3. Arrive at the stockpile area, ensure workers, staff and supervisors are aware of the activities.
4. Perform the terrestrial scans according to the method described in section 3.4
5. Perform the aerial survey according to the method described in section 3.5.
6. Sign off and leave the job site. Return to the office and begin processing data.

3.3.3 Participants

For this experiment there are three distinct responsibilities:

- A surveyor who will be performing the terrestrial scans and conducting the aerial survey.
- A UAV controller who will be present to ensure the safe operation of the UAV in accordance with CASA regulations.
- An evaluator who will be taking notes during the course of the experiment.

The surveyor can perform the role of the evaluator, therefore requiring a minimum of two people.

3.4 Data collection: Terrestrial Laser Scanner

This section will describe the method of survey and data processing required to generate a digital terrain model (DTM) of the coal stockpile area with a TLS, specifically the Reigl VZ-1000 TLS with the RiScan Pro software.

3.4.1 Equipment

1. **Riegl VZ-1000 Terrestrial Laser Scanner**

The Riegl VZ-1000 (Fig. 3.1) is a long-range, high accuracy laser scanner. Its specifications are (Reigl 2013):

- Accuracy of measured points: 8mm
- Precision of measured points: 5mm
- Maximum measurement range:
    - Reflectivity ≥90%: 1400m
    - Reflectivity ≥20%: 700m
- Measurement rate at 70kHz: 29,000 measurements per second

Among the range of laser scanners on offer today, the VZ-1000 represents the middle-tiered model in terms of range, accuracy and features. There is now a VZ-6000 model available with a range up to 6000m.

Figure 3.1: Riegl VZ-1000
(Reigl 2013)

2. **Trimble R8 GNSS Receivers**

The Trimble R8 GNSS receiver (Fig. 3.2) will be used to measure the control points that orientate the scanner. Two receivers will be required: one to act as the survey base station, and a second to act as the "rover" unit. The specifications of the R8 are (Trimble 2013):

Real-Time Kinematic Surveying:

- Horizontal accuracy: ±8mm + 1 ppm RMS
- Vertical accuracy: ±15mm + 1 ppm RMS

Figure 3.2: Trimble R8 GNSS Receiver
(Trimble 2013)

3. **Trimble HPB450 radio repeater**

The HPB450 radio repeater (Fig. 3.3) will be required to transmit the corrections broadcast from the survey base station to the rover.

Figure 3.3: The HPB450 radio repeater (without antennae or battery)

4. **Miscellaneous Items**

The miscellaneous items which will be required to complete the stockpile survey are:

- 3x Tripods (one for the GNSS base station, a second for the radio repeater and a third for the laser scanner)
- 1x Two metre survey staff for GPS measurements

- 1x Offset tape
- 1x Cylindrical backsight reflector
- An external hard drive to backup the data

3.4.2 Survey method

Before surveying a coal stockpile with a terrestrial laser scanner, there are a number of considerations to take into account which includes measurement quality, point density, overlap requirements and operator safety.

The low reflectance of coal must be taken into consideration by ensuring scan positions are not setup too far from the intended target. The reflectivity of coal typically lies between 0% and 3% (Schlumberger 2013). According to Riegl's graph showing maximum measurement ranges (Fig. 3.4), this means that scan positions should be situated no further than 300m from the intended target (by interpolation for the 70kHz program).

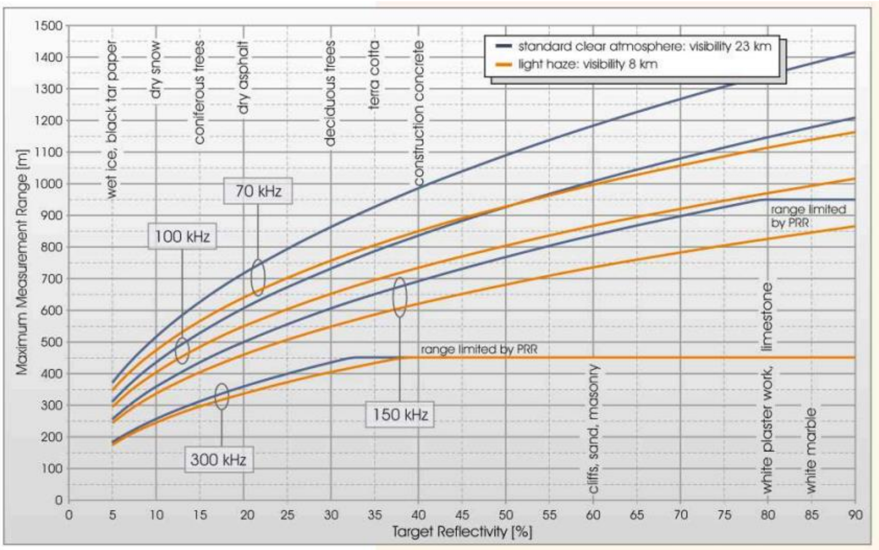


Figure 3.4: A chart describing the maximum distance for return signal with the VZ-1000, for different levels of target reflectivity

(Reigl 2013)

The safety of the operator is also a primary concern. Coal stockpile areas are usually very active, with large machinery and haul trucks operating in close proximity. To ensure operator safety, the hazards have been assessed in a risk assessment where the most appropriate and effective risk management strategies have been proposed.

The first step in scanning the coal stockpile is site mobilization. This means ensuring that all the equipment and personnel arrive on site safely, and that the site manager is aware of the activities. The control points for both survey methods (UAV and laser scanning) are to be acquired through the use of RTK GPS; so the second step is to set-up the RTK base station and radio repeater. Once this has been achieved, the work flow will follow the process described below. This work process is designed for a survey party of one surveyor. As the operation of the UAV only requires one person to operate, this will make the two methods more comparable.

1. Perform a visual survey of the area to be scanned
    i. Note any hazards (machinery, haul trucks).
    ii. Locate optimum scan positions that will achieve the desired measurement quality, limit the possibility of 'shadow' and ensure the safety of the operator.
    iii. Decide on the best sequence to perform the scans in.
2. Setup at the scan position
    i. Perform a visual check to ensure that the scan position is no more than 300 metres away from the targeted stockpile, to ensure adequate signal return, and to ensure the backsight is visible.
    ii. Extend tripod legs to the highest practical height (i.e. still capable of seeing the plate bubble).
    iii. Ensure legs screws are securely tightened.

   iv. Ensure tripod feet are firmly planted into the ground and that the tripod is approximately level.
   v. Remove scanner from its case and place it upon the tripod, ensuring the base screw is securely tightened.
   vi. Level the scanner by adjusting the legs and the tribrach screws.
   vii. Connect the scanner's battery pack.
   viii. Connect the scanner to the laptop controller via data cable.
3. Survey the control points
   i. Place the receiver on top of the backsight and ensure the correct antenna height is set in the controller.
   ii. Ensure that the point name is correct and the point is coded correctly and then store the position of the backsight.
   iii. Change the antenna height to the correct value to measure the scanner's optical centre.
   iv. Ensure that the point name is correct and the point is coded correctly (i.e. IP for Instrument Position).
   v. Place the receiver on top of the scanner (taking care not to disturb the tripod legs/scanner) and store the instrument position.
4. Perform the panoramic scan
   i. Ensure that the correct settings are entered into the software.
   ii. Perform a final visual check of the area to ensure that no obstructions (machinery, haul trucks, light vehicles) have entered the area.
   iii. Perform the panoramic (360 degree) scan.
   iv. When scan is complete, check the data for shadows and other potential faults.
   v. If an issue with the data is discovered, re-do the panoramic scan.

   vi. If the issue persists, check the scan settings or consider an alternative scan position.

5. Fine-scan the backsight
   i. Locate the backsight reflector in the scan preview, and use the mouse cursor to insert a “tie point” at the centre of the reflector.
   ii. Ensure that the correct reflector type has been set for the tie point (i.e. cylindrical reflector with a radius and height of 100mm).
   iii. Perform a fine scan of the tie point/backsight reflector.
6. Pack-up scanner
   i. Disconnect the laptop controller and the battery pack
   ii. Unscrew base screw and remove the scanner from the tripod, and place the scanner back into its case.
   iii. Collapse tripod legs.
   iv. Replace equipment into vehicle, and relocate to the next scan position.
7. Relocate to the next scan position
   i. Ensure that any nearby machinery and/or haul trucks are aware of your movements.
   ii. Travel to the next scan position as identified in the visual survey carried out in Step 1.
8. Proceed to scan the remaining stockpile area
   i. Follow Steps 2-7 until the stockpile area is completely surveyed.
   ii. If it is discovered that additional scans will be required to complete the survey, ensure a second visual survey of the area is performed to identify the safest possible way of acquiring the missing data.
9. Backup data
   i. Once the survey is complete and the scans have been verified, backup the data to an external hard drive.

10. Site demobilization
    i. Once the survey is complete and the data is verified, inform the coal stockpile operators and the site manager that you are finished and leaving the job site.

3.4.3 Data processing technique

Once the survey is complete, the raw data must be properly processed before it can be used to create a surface model. Processing the raw data involves data registration, post-processing, adjustment, exportation, point cloud filtering and finally triangulation. But before the process is discussed in detail, the software will be discussed to explain the processing environment.

Software Environment

The VZ-1000 is controlled and operated through the RiScan Pro software package. Each survey with the VZ-1000 begins by creating a new “project” within RiScan. All measurements are then organized and stored within RiScan’s project structure, and managed by the user through RiScan (see Fig. 3.5 showing the RiScan interface).

RiSCAN includes a number of tools which allow the user to select, manipulate and delete points if necessary. However, RiScan does not provide adequate functionality to thoroughly analyse DTMs, so the data must be exported and modeled in separate dedicated modeling software.

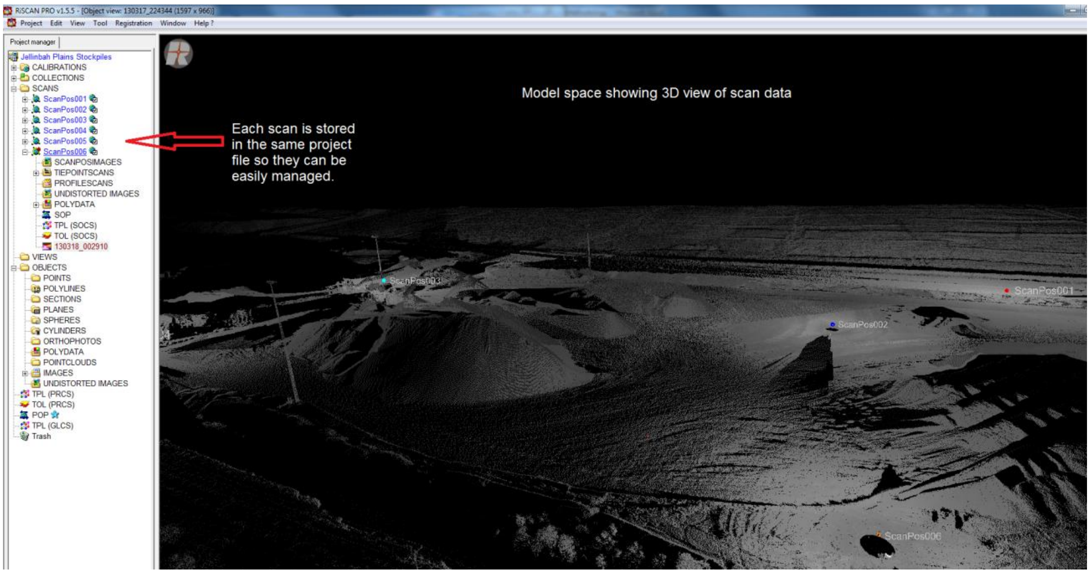


Figure 3.5: The RiScan pro interface

1 - Data Transfer

There is the option to process the data using the laptop controller; however it is more practical to perform the processing on a more powerful machine. In the office, the entire project file is transferred to the hard drive of a desktop computer (PC) via a data cable (LAN is most convenient) or an external hard drive. It is good practice to leave a copy of the project on the laptop or external hard drive as a backup.

In addition to the project file, the surveyed coordinates of the control points must also be transferred onto the PC. This is a simple matter of exporting the coordinates from the data controller as a text file (i.e. comma-separated values, or CSV) using the controller software, and then transferring the text file to the PC through the use of a USB cable.

2 - Data Registration

Before registration, each scan is on an individual "scanner's own coordinate system" (SOCS) (see Fig. 3.6). As can be seen, prior to registration none of the scans "line-up". In order to register the data on a common, recognised coordinate system (such as MGA), the coordinates of the control points must be imported into the project file, and tied to the corresponding *instrument positions* and *backsight positions*. Note that the backsight positions were identified within the scan itself during the field work, when the reflector was fine scanned.

If the control points were named and coded correctly during the field work, then registration is a simple process and is completed relatively quickly. It is prudent to merge all of the scans into the one 3D view before post-processing, to ensure that all control points have been registered correctly. If a registration error existed, it is immediately visible in the 3D view (as shown in Fig. 3.7) and can be promptly corrected.

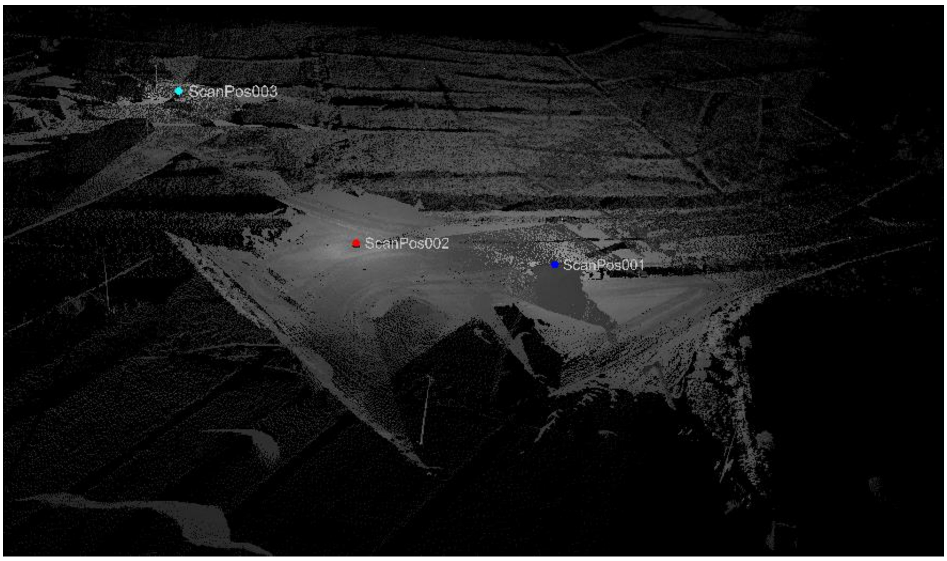


Figure 3.6: Displaying scan data before registration, on "SOCS". Notice that none of the point clouds "line-up" – they appear to be completely disoriented.

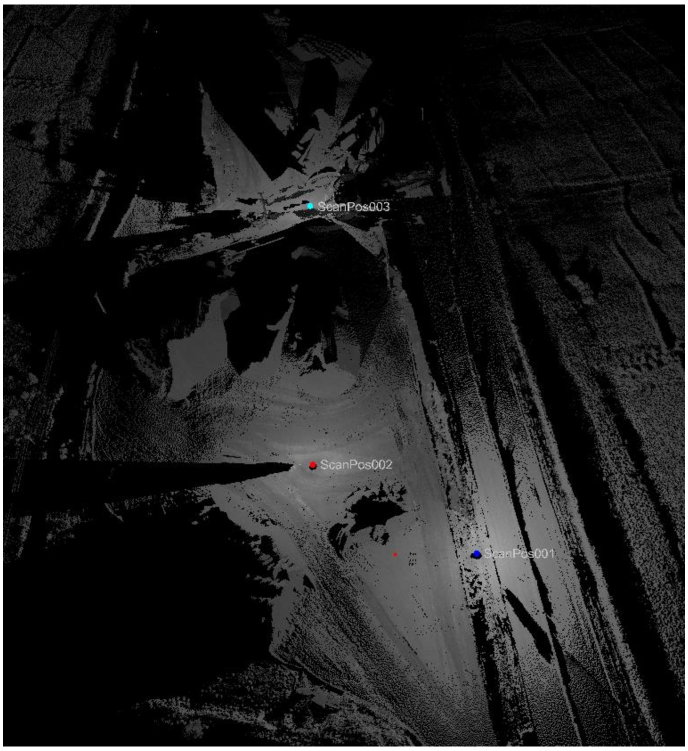


Figure 3.7: Displaying an error in orientation. Notice scan position 1 and 2 appear to line-up, however scan position 3 appears to be disoriented.

3 - Post-processing

It is essential to "clean" the data prior to performing a multi-station adjustment. Sometimes erroneous points will exist because the laser scanner has recorded an incorrect range. This occurs if the laser strikes a surface at a poor angle, or if the surface is wet. For best results these points must be deleted from the point cloud before any processing takes place. This is simply done in RiScan by selecting the bad points, which are easily seen in the 3D view, and deleting them from the file. There are also a number of automatic point filtering processes that can be used to clean the data.

Once the bad points are removed, the point cloud for each scan must be reduced to plane surfaces (triangulated) (Fig. 3.8). This must be done so that the software can find identical points and surfaces in each point cloud during the multi-station adjustment.

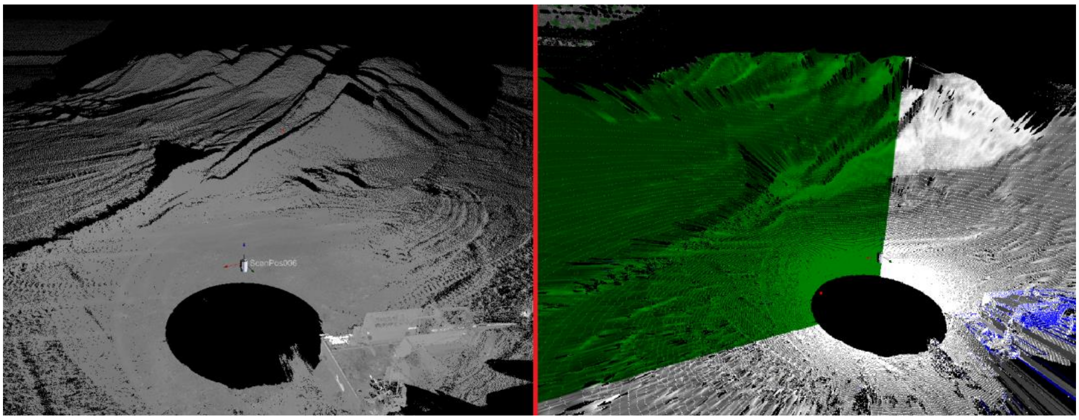


Figure 3.8: On the left is a point cloud ready for post processing. On the right, the point cloud has been reduced to plane surfaces, and is ready for a multi-station adjustment.

4 - Multi-Station Adjustment

Once the data has been processed, it is ready for a multi-station adjustment. A multi-station adjustment is essentially a least-squares adjustment of each scan position and its orientation. As mentioned earlier, data registration (step 2) orientates the scan data so that they all line up to form a single, coherent point cloud. However, alignment errors still exist due to setup and measurement errors. These errors must be reduced so that a reliable surface model can be formed.

RiScan finds common points and surfaces between overlapping scans and uses the differences between these to determine corrections to the position (X, Y and Z coordinates) and the orientation (Roll, Pitch and Yaw) of the scanner. The program performs several iterations of this process to determine the best overall fit for the scan positions and their orientation. Once the multi-station adjustment is complete, RiScan reports a standard deviation, enabling the user to quickly judge the accuracy of the initial scans. If the value is too high then an error exists which must be rectified, or the scans must be repeated.

5 - Exportation from RiScan and importation into point cloud processing software

With the multi-station adjustment complete the scan data can be exported from RiScan as a text file. This file can then be imported into dedicated point cloud processing software. In this case, Terrasolid software is used as a plug-in to the Microstation CAD environment to filter and model the point clouds.

6 - Point filtering

At this point the point cloud is still unusable because it contains "noise". Noisy data contains features which are not intended to be modeled, such as power poles, trees, vehicles, machinery etc.

The best way to remove noise is with an automatic point filtering program. "Terrascan" (Terrasolid software) can be used to categorize points into feature categories (such as vegetation, power poles etc.) based on their relationship with the points around them (i.e. via neighborhood analysis), allowing the user to select which features they require. In this case, "ground points" represent the feature which will be required for modeling of the stockpiles.

7 – Triangulation

With the points orientated, cleaned, adjusted and filtered they can now be triangulated to create a digital terrain model.

3.4.4 Possible sources of error in data

Before analyzing the results it is prudent to anticipate the error or uncertainty that will inevitably exist, originating from random factors that cannot be eliminated. In this case, these random errors will originate from:

1. The GNSS receiver when storing the control points, including centering and plumbing error, and the uncertainty of the GNSS receiver itself due to initialization and atmospheric errors.
2. Plumbing error of the laser scanner, and the accuracy of its laser measurements.

All of these errors will propagate in the final results (i.e. each point stored by the laser scanner).

3.5 Data collection: eBee UAV

This section describes the survey method and data processing techniques used to generate a digital terrain model of the coal stockpile area with the eBee UAV and the "Postflight 3D" software. In accordance with CASA regulations, a licensed operator (in this case, the equipment provider) will be present at all times during the test flight.

3.5.1 Equipment

1. The eBee UAV

The eBee UAV described in section 2.4 will be used to perform the aerial survey of the coal stockpile area.

2. Trimble R8 GNSS Receiver and radio repeater

RTK GNSS receivers will be used to coordinate the ground control points for the aerial survey. The Trimble R8 GNSS receivers described in section 3.3.1 will be used, along with the HPB450 repeater radio to transmit the corrections from the survey base station.

3. Laptop computer with Postflight Terra 3D software installed

The Postflight Terra 3D software will be used to perform initial processing, providing a quality check on the data before closing the experiment and leaving the project site.

4. Miscellaneous

The miscellaneous items which will be required to complete the aerial survey are:

- 2x Tripods (one for the GNSS base station, a second for the radio repeater)
- 1x Two metre survey staff for GPS measurements
- High visibility survey paint for marking ground control points
- An external hard drive to backup the data

3.5.2 Survey method

The first step will be site mobilization and the establishment of a base station for the RTK GNSS. Once this has been completed the survey can proceed using the method described here. A second risk assessment has been prepared to ensure the safety of this operation.

1. Prepare flight plan

   i. Prepare a flight plan for the area in accordance with the information gathered in section 2.4.2.

2. Site mobilization
    i. In this step it must be ensured that the equipment and personnel arrive on site safely.
    ii. Ensure that the site manager is appropriately informed of the activities and that all personnel surrounding the work site are informed, and that the activities will not injure or inconvenience nearby workers.
3. Assess the area for optimum photo control locations
    i. Assess the area for any immediate hazards such as machinery and vehicles.
    ii. Select locations for the ground control that will not be disturbed by machinery or other personnel during the flight, and are clearly visible from the sky.
4. Place photo control
    i. Place the photographic control in the pre-selected location, ensuring that coal pad workers are properly informed of your activities.
    ii. Use the GNSS rover to record the coordinates of the control point.
5. Launch the eBee on the designated flight plan
    i. Monitor weather conditions while the eBee is in flight.
    ii. If wind speeds get too high the survey will need to be stopped as a safety measure.
6. Collect eBee, transfer the data and pack up
    i. Once the eBee has completed the flight, retrieve it from its landing spot.
    ii. Download the data onto a laptop computer with the Postflight Terra 3D software installed, and backup the data onto an external hard drive.

   iii. Place the eBee into its protective case and pack up the remaining equipment.

7. Perform rapid processing to check the data

   i. Before leaving site, use the Postflight software on a laptop computer to perform the initial/rapid processing. This will provide a quality check on the data to ensure it can be used for the project.

8. Return to the office

   i. Ensure that the workers and the site manager have been informed that the exercise has been completed and that you are now leaving site.

3.5.3 Data processing technique

Software environment

Processing takes place with the Postflight Terra-3D software developed by senseFly. Similar to RiScan, Postflight organizes all of the data into a "project structure", and the project is managed by the user through the software interface. Processing is essentially a point-and-click process, where many of the settings are automatically determined after the initial processing stages.

1 – Georectification of images

In order for stockpile volumes to be calculated with the eBee DTM it must be related to the same coordinate system as the stockpile's base surface, that is; it must be georectified. To accomplish this, the ground control points (GCPs) (established in step 4 of the field process) are used to scale and coordinate each pixel of the photographs (Georgic & Wagner 2003).

Inserting GCPs with the Terra-3D software is performed by the following steps:

1. Export the coordinate file from the GNSS controller as a text file (such as a comma-separated values file).
2. Import the coordinate file into Terra-3D
3. Select the coordinate system (In this case GDA/MGA94 Zone 55)
4. Manually insert control points by locating the targets in the photographs, selecting the appropriate control point from control list that was previously imported, and clicking upon the centre of the target in the photograph (Fig. 3.9).

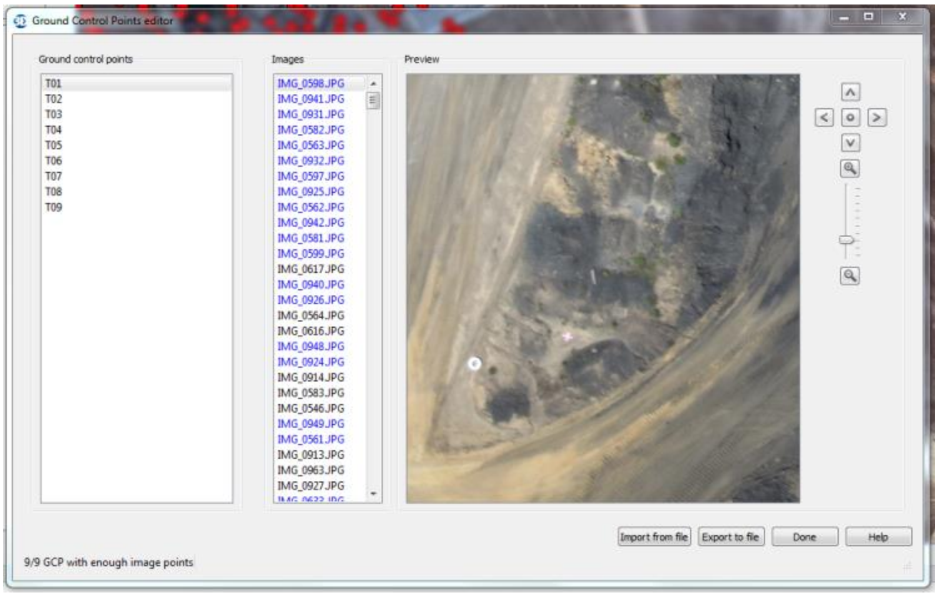


Figure 3.9: Control point insertion is done by selecting from the list of available control points and identifying its location on the photograph. On this photograph, the control point is the white and pink cross located near the centre of the image.

2 – Initial processing

During initial processing, aerotriangulation and block adjustment procedures are executed. Once this stage is complete the software produces a detailed quality report which can be used to identify bad photos and incorrect control points.

3 – Point cloud densification

This is an optional step included in the Terra 3D software. During initial processing the aerotriangulation procedure produces a number of 3D points which it uses for adjustments, however in most cases this is not enough for a DTM to be created. Point cloud densification increases the number of 3D points in preparation of DEM generation.

4 – Orthomosaic and DEM generation

After densification a point cloud can be generated at a specified resolution (i.e. a point spacing, or distance between points of 15cm, 10cm, 5cm, etc.). For maximum accuracy it is recommended that the DEM resolution is set to match the photographic resolution. That is, if the photographic resolution is 3.5cm per pixel, then the DEM resolution can be set to a point spacing of 3.5cm. However, it will be discussed in the results chapter that this is not really beneficial to accuracy.

5 - Exportation from Terra 3D and importation into point cloud processing software

Terra 3D does not offer any point cloud processing tools (aside from generating one), so the point cloud must be exported as a text file and imported into dedicated point cloud processing software. In this case, Terrasolid software is used as a plug-in to the Microstation CAD environment to filter and model the point clouds.

6 - Point filtering

At this point the point cloud is still unusable because it contains “noise”. Similar to the point cloud obtained from the terrestrial laser scanner, it must be filtered in order to remove features which should not be modeled.

7 – Triangulation

The point cloud generated from the photographs can now be triangulated to form a DTM.

3.5.4 Possible sources of error in data

The error in the resulting DTM will depend upon a number of factors, some of which are described in section 2.7:

1. The error of the GNSS receiver used to store the control points
2. The accuracy/quality of the camera orientation
3. Image quality/resolution
4. The quality of the processing software

However, considering the size of the eBee and the low flying height required under the CASRs, the effects of platform movement could be a considerable source of error. Although the eBee is programmed to stabilize before taking a photo, it is light, which means it will be easily disorientated by gusts of wind. The accuracy the processing results will rely heavily upon the accuracy of the on-board sensors when recording the flying height, yaw, pitch and roll (Fig. 3.10) at the time the photograph was taken.

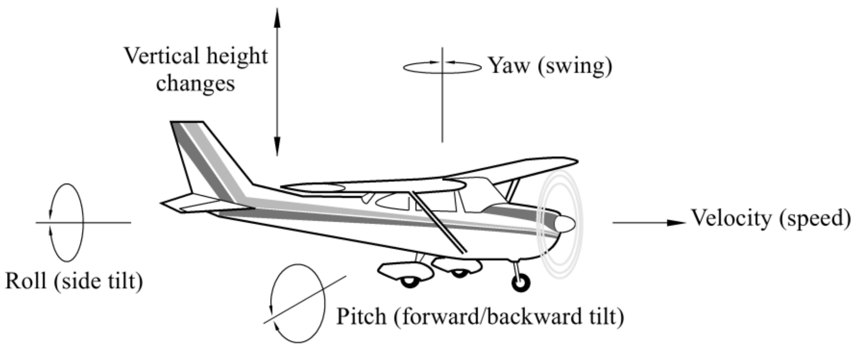


Figure 3.10: Movements of an aircraft while in flight

Apparent image motion (AIM) is also a danger considering the low flying height (less than 120 metres) of the UAV. However, this is reduced by the relatively slow ground speed of the eBee (approximately 18 m/s) (USQ 2012).

3.6 Summary

This chapter has described the nature of the surveying application that is being evaluated in this project—a coal stockpile survey. The baselines (i.e. minimum performance requirements) have been described, and a basic outline of the experiment has been provided.

Most significantly it has described two different survey methodologies that will be used to complete the project. First, the method of survey using a terrestrial laser scanner, and secondly, the method of survey using an unmanned aerial vehicle. The field and office procedures of both have been outlined in detail to ensure the safety and success of the operation.

CHAPTER 4

Results

4.1 Introduction

The previous chapter described the preliminary details of the evaluation, and described the survey methods that were used to generate a digital terrain model with the eBee and a Terrestrial Laser Scanner (TLS). This survey was successfully performed on the 18th of March, 2013. The coal stockpiles at Jellinbah coal mine near Blackwater (Queensland) were surveyed and digital terrain models (DTMs) were successfully created.

In this chapter, the data obtained from the survey is analysed. The two DTMs (the UAS and the TLS DTMs) are compared and the results are reported. The final section of this chapter also discusses less technical observations relating to efficiency and usability. The results of this analysis then form part of the overall evaluation of the eBee.

4.2 Order of events and adverse conditions

The order of events, including adverse events which affect the results of the survey were:

1. Site arrival, safety inspection and mobilization
2. Terrestrial scan of stockpile successfully completed
3. Aerial survey with UAV begins
4. *Bulldozer begins working on stockpile 2 (SP2)*
5. Aerial survey with UAV successfully completed

6. Site demobalization

Fig. 4.1 is an aerial photograph of the stockpile area showing the different stockpiles that were surveyed. Stockpile 2 (SP2) was significantly modified by a bulldozer during the course of the survey, which must be kept in mind when analyzing data from this area.

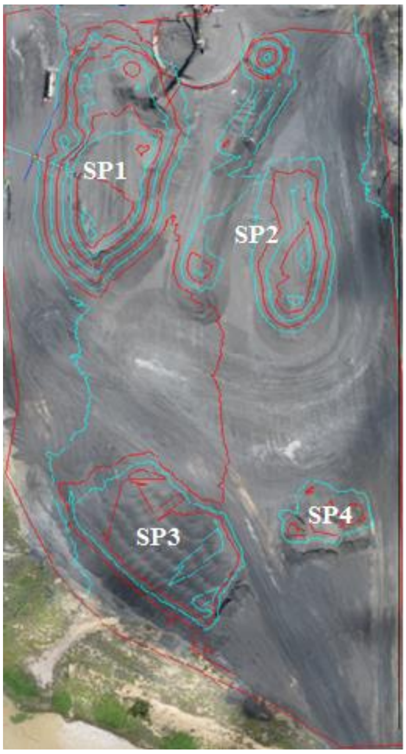


Figure 4.1: The stockpile area surveyed with the eBee UAV and VZ-1000 terrestrial laser scanner. “SP” stands for “Stock Pile”.

4.3 Initial Processing and DTM generation

This section reports the results of the preprocessing stages of each survey method. The preprocessing results will describe the internal quality of the DTMs as discussed in section 2.8.

4.3.1 Pre-processing of the terrestrial laser scans

The preprocessing results for the terrestrial scans indicate that the data has been properly and accurately acquired, and is suitable for the purpose of this evaluation. This is shown by the results of the multi-station adjustment. During a multi-station adjustment the software locates common points between each scan, and uses these common points to determine adjustments in the position and orientation for each scan position. After adjusting the position and orientation, the software then analyses the adjustment by measuring the remaining distances between the common points. The results of this analyses can be seen in the histogram of residual frequencies (Fig. 4.2).

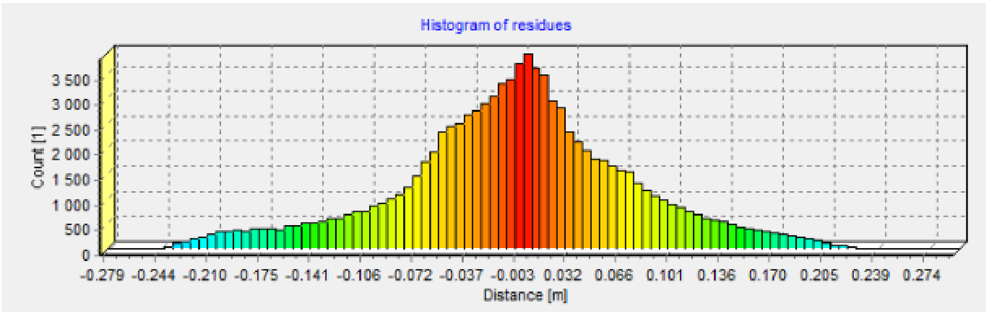


Figure 4.2: Screen capture of the histogram of residuals from the multi-station adjustment

The shape of the histogram indicates that the residuals are, approximately, normally distributed and that the majority of the common points used in the adjustment are in good agreement, as seen in Table 4.1. Table 4.1 displays the final results of the adjustment. The standard deviation of 0.0793m is calculated using the residuals displayed in Fig. 4.2. The deltas represent the adjustments made to the scan positions and orientations. Note that the scan positions (X, Y and Z) were locked during the adjustment because these have been accurately fixed by RTK GPS, and have therefore remained unadjusted.

While these results are not the best (normally a standard deviation less than 0.05m is expected), they are adequate for the calculation of stockpile volumes and suitable for comparison with the UAV DTM. Although, these results must be kept in mind when performing these comparisons.

Table 4.1: Statistical summary of the multi-station adjustment

	Change in position (m)			**Change in orientation (deg)**		
Name of Scan	Δ X	Δ Y	Δ Z	Δ Roll	Δ Pitch	Δ Yaw
ScanPos001	0	0	0	0.008	-0.005	-0.007
ScanPos002	0	0	0	-0.001	0.015	0.156
ScanPos003	0	0	0	0.001	0.011	0.029
ScanPos004	0	0	0	0	-0.001	0
ScanPos005	0	0	0	0.001	-0.002	0.026
ScanPos006	0	0	0	0	0	0.001

Standard Deviation of Residuals	0.0793

4.3.2 The DTM of the terrestrial scans

With the preliminary processing providing positive results, the next stage of data processing was executed. First, the point cloud was filtered using an automated point filtering process included in the TerrScan software as described in section 3.3. Fig. 4.3(a) displays the point cloud after it has been filtered. The orange and red points represent ground points, while the green points represent vegetation and structures. Note the three power poles which have been effectively isolated by the filtering process.

Fig. 4.3(b) shows the ground points after the unwanted data has been removed. The ground points are then meshed to form a digital terrain model. The circled areas in Fig. 4.5(c) indicate sections of the model that are shadowed. Unfortunately due to safety reasons, scans could not be performed from the tops of the stockpiles, so it was inevitable that there would be shadow in these top sections.

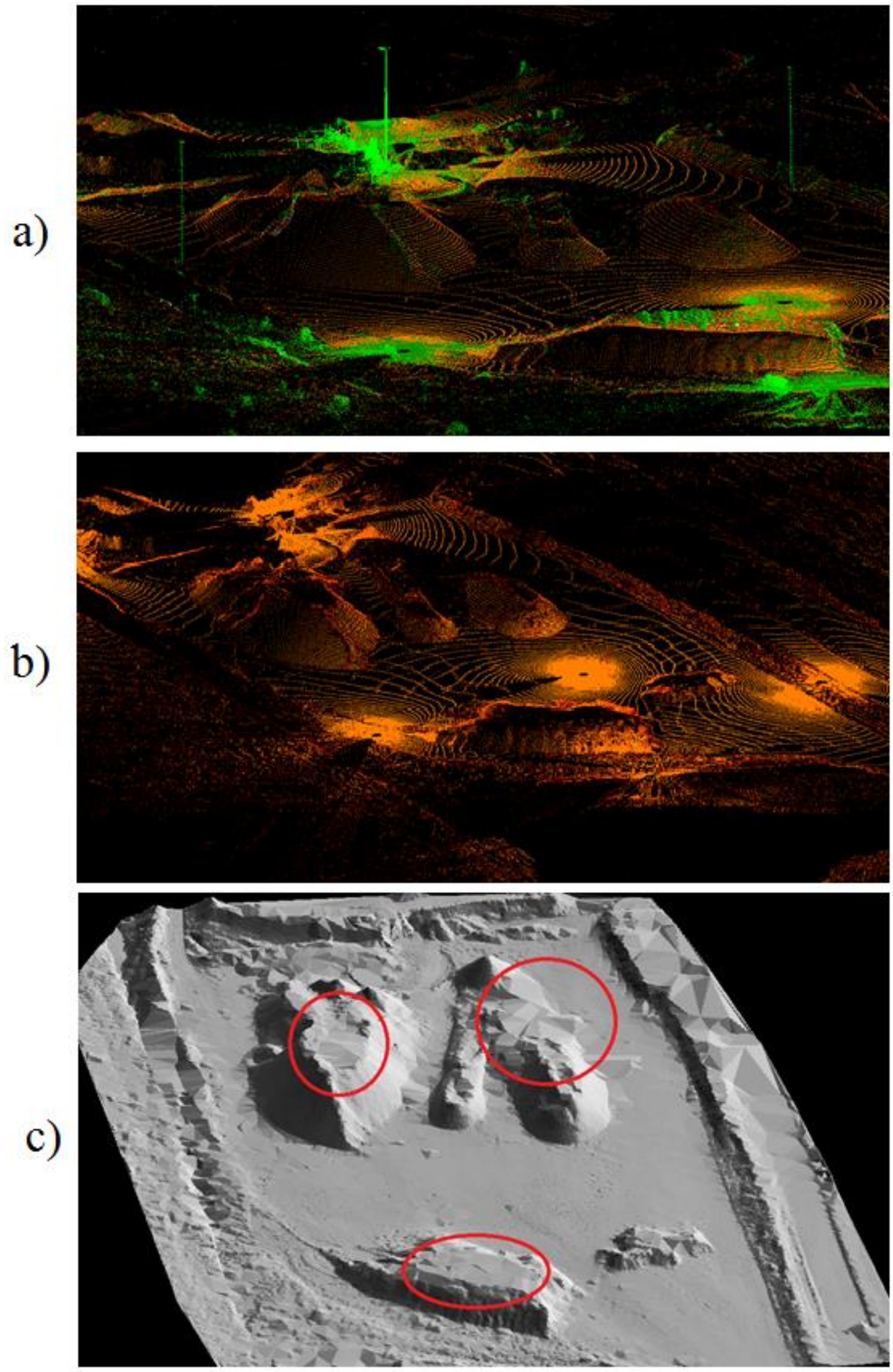


Fig 4.3: (a) The point cloud filtered by the automatic point filtering software.
Note the power poles (green) that have been effectively isolated.
(b) The point cloud once the ground points have been isolated.
(c) The DTM formed with the ground points. The circled areas indicate “shadow”

However, apart from these shadowed sections the DTM appears to have formed well. The toes (i.e. bottom) of each stockpile are clearly defined and there does not appear to be any "rogue points" (i.e. on zero elevation, etc.) remaining in the point cloud.

4.3.3 Initial processing of the eBee photographs

Initial processing of the eBee photographs involves an aerotriangulation process which adds additional 3D points for control densification, followed by a bundle adjustment of the geo-located photographs. In Fig. 4.4, the locations of the 557 photos collected during the eBee's flight are shown as an overlay on a google earth image of the stockpile area. In Fig. 4.4 it can be seen that the dots are scattered, instead of adhering to straight, perpendicular lines. This indicates a large degree of platform movement during the flight.

During the bundle adjustment the internal camera parameters are optimized, and used in conjunction with the photo orientation information (GPS coordinates, heading, pitch and roll) stored in the flight logs (also called "geo-tags") to optimize the camera positions (SenseFly 2013b). In Fig. 4.5, the difference between the initial camera locations and the optimized locations are displayed. For many of the photographs the locations do not differ significantly, with one exception as indicated by the blue circle in Fig. 4.5. Reasons for this particular photo being in such poor agreement may be (SenseFly 2013b):

1. High noise in the GPS receiver
2. Errors in the geo-tagging process

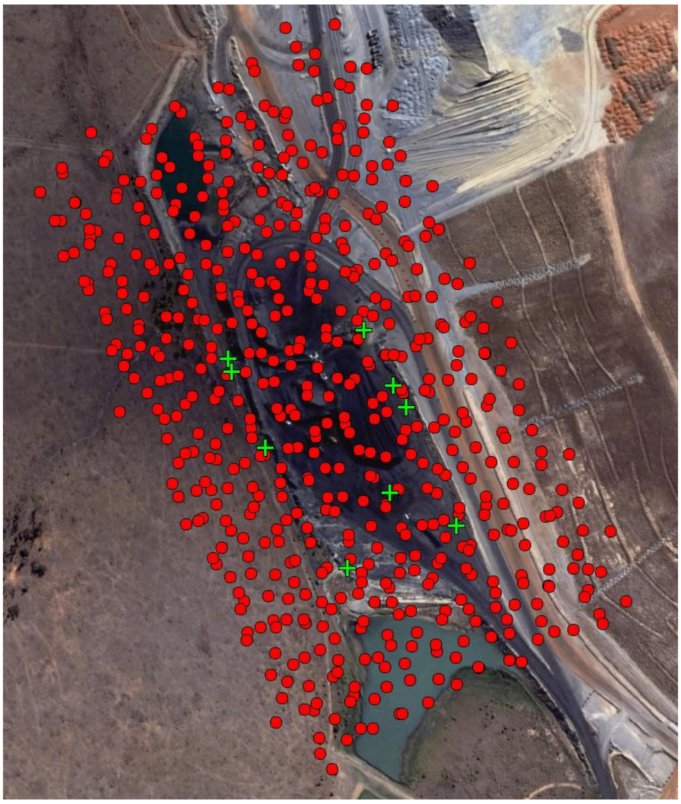


Figure 4.4: Geolocated photographs are represented by red dots. The green crosses represent the location of ground control points.

Observing Fig. 4.6 it can be seen that the incorrectly located image (called IMG_1041.jpg) has not been correctly geo tagged (i.e. no value for latitude or longitude, etc.), which explains why this photo is in such poor agreement. Although the results of the bundle adjustment indicate that this photo has had no significant effect on the quality or the accuracy of the processing (indicating that its position had been correctly optimized), the offending photograph was deleted to avoid any more potential problems.

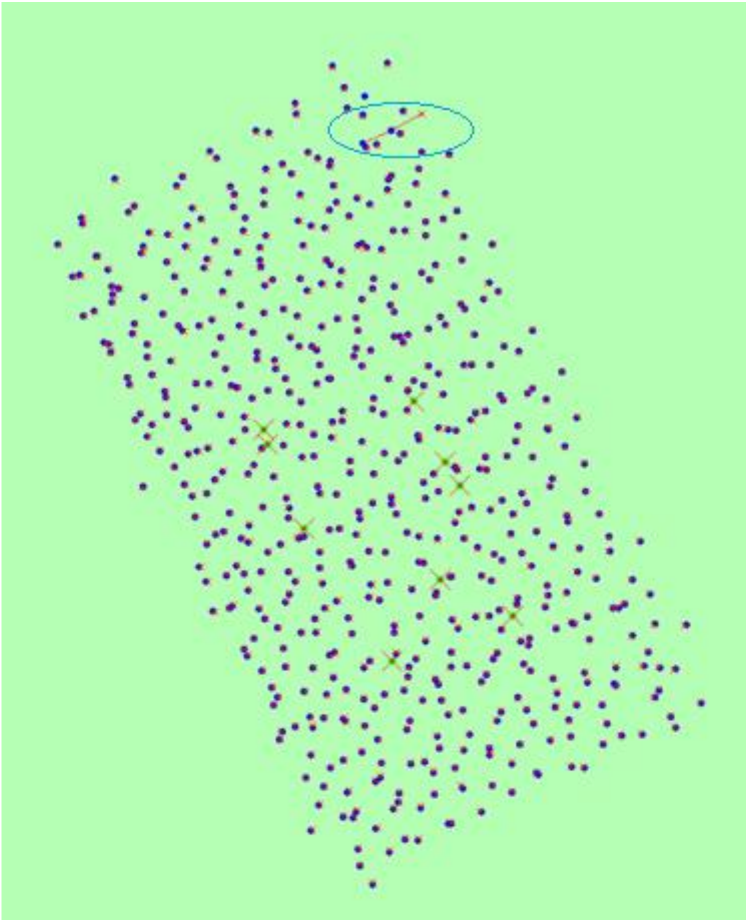
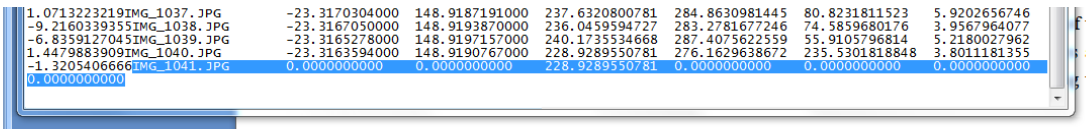


Figure 4.5: Geo-tagged locations v. optimized camera locations. Blue dots represent optimized positions while red crosses indicate the original positions of photographs. Note the blue circle indicating a “bad” photo.



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1.0713223219IMG_1037.JPG    -23.3170304000  148.9187191000  237.6320800781  284.8630981445  80.8231811523   5.9202656746
-9.2160339355IMG_1038.JPG   -23.3167050000  148.9193870000  236.0459594727  283.2781677246  74.5859680176   3.9567964077
-6.8359127045IMG_1039.JPG   -23.3165278000  148.9197157000  240.1735534668  287.4075622559  55.9105796814   5.2180027962
1.4479883909IMG_1040.JPG    -23.3163594000  148.9190767000  228.9289550781  276.1629638672  235.5301818848  3.8011181355
-1.3205406666IMG_1041.JPG   0.0000000000    0.0000000000    228.9289550781  0.0000000000    0.0000000000    0.0000000000
0.0000000000
```

Figure 4.6: Geo-tag entry for IMG_1039 displaying that no latitude, longitude, altitude on WGS84, heading, pitch or roll has been stored.

The results of the block adjustment verify the quality of the photographs and the initial processing. The optimized camera parameters are critical to the accuracy of the process, and are easily checked by observing the optimized values for the principal points. As the principal point represents the centre of the photograph, the optimized position should be equal to half the camera resolution (3456x4608 pixels). It can be seen in Fig. 4.7 that the principal values do not differ wildly from this condition. Note that there are two sets of camera parameters because the "working project" is actually the combination of two different flight plans (due to the utilization of perpendicular flight lines). The fact that these two separate groups of results agree so closely provides and additional check.

Internal Camera Parameters CanonIXUS125HS_4.3_3456x4608 sensor dimension: 6.17 4.63 [mm]

	Focal length	Principal point X	Principal point Y	RD 1	RD 2	RD 3	TD 1	TD 2
initial values	3274.810 [pix] 4.386 [mm]	2304.000 [pix] 3.086 [mm]	1728.000 [pix] 2.315 [mm]	-0.048	0.045	-0.016	-0.003	0.008
optimized values	3336.364 [pix] 4.469 [mm]	2398.941 [pix] 2.959 [mm]	1773.484 [pix] 2.254 [mm]	-0.044	0.052	-0.022	0.003	0.009

Internal Camera Parameters CanonIXUS125HS_4.3_3456x4608_merge_jellinbah_1 sensor dimension: 6.172 4.629 [mm]

	Focal length	Principal point X	Principal point Y	RD 1	RD 2	RD 3	TD 1	TD 2
initial values	3274.810 [pix] 4.386 [mm]	2304.000 [pix] 3.086 [mm]	1728.000 [pix] 2.315 [mm]	-0.048	0.045	-0.016	-0.003	0.008
optimized values	3320.060 [pix] 4.447 [mm]	2401.248 [pix] 2.956 [mm]	1777.951 [pix] 2.248 [mm]	-0.041	0.040	-0.013	0.003	0.008

Figure 4.7: Optimized camera parameters produced during the bundle adjustment.

The bundle adjustment determines a best fit for the photographs. Once it has done this, the Postflight 3D software determines an "error" for the ground control coordinates by calculating a difference between the position of the GCP "as-clicked" by the user (i.e. the pixel location) and the location of the GCP as it is re-projected onto the adjusted photographs—which are now defined on the global coordinate system. The error for the 9 ground control points used for the aerial survey can be seen in Table 4.2.

Table 4.2: Error in ground control points

GCP name	error X (m)	error Y (m)	error Z (m)
GCP: T01	0.017	0.016	0.005
GCP: T02	0.006	0.002	0.05
GCP: T03	0.02	0.007	0.022
GCP: T04	0.006	0.02	0.012
GCP: T05	0.007	0.004	0.012
GCP: T06	0.006	0.007	0.011
GCP: T07	0.001	0.001	0.027
GCP: T08	0.008	0.012	0.03
GCP: T09	0.025	0.019	0.001
Mean	0.01	0.01	0.019
Std. Dev.	0.007	0.007	0.014

The results are satisfactory, with a max Z-error of 27mm indicating that the photographs have been correctly processed and are able to be used for the generation of a DTM.

4.3.4 Generating a point cloud with the UAV photographs

During the initial processing, a limited number of 3D points are triangulated in order for the necessary adjustments and calibrations to be carried out. Before generating a 3D point cloud, Postflight Terra 3D performs this process again—but more rigorously, and computes a 3D point for every fourth pixel in order to maximise the accuracy of the DTM.

Once this is completed, a 3D point cloud can be generated. The Terra-3D software manual recommends the resolution for the point cloud be set to equal the ground resolution of the photographs (3.56 cm in this case), meaning that 3D points will be approximately 3.56cm apart in the point cloud. In Fig. 4.8 the result can be seen; notice that the cloud is much denser than the terrestrial scans, however there are obviously large gaps (shadow) in the data.

Figure 4.8: The point cloud generated using the UAV photographs

Again the point cloud must be filtered to remove any unwanted features. After running the filtering process it appeared that the software had incorrectly classified a number of features. Notice in Fig. 4.9, that what is clearly the top of a coal stockpile has been classified as “high vegetation”. It appears that the photo processing software has not generated any 3D points at the base of the stockpile—which may be the cause of the incorrect classification.

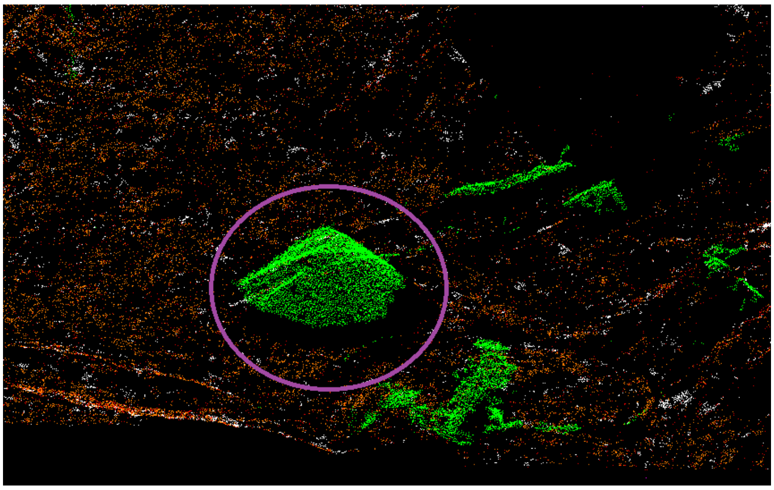


Figure 4.9: The top of a coal stockpile has been classified as vegetation because of the lack of 3D points at the base of the stockpile.

The filtering process classifies a point based on its relationship with other points within a specified search radius (i.e. 0.010m radius). Because of the lack of points at the base of stockpile, the software has been unable to determine the correct relationship between the stockpile and the ground, which has caused the software to recognize the top of the stockpile as the canopy of a tree. While increasing the search radius may help to eliminate this problem, it results in other areas being incorrectly classified, and also increases the processing time. So to rectify this, the points were simply selected and reclassified manually.

4.3.5 Generating a DTM from the UAV point cloud

With the points correctly classified a DTM can be produced with the filtered data. In Fig. 4.10, it can be seen that where gaps in the data exist there has been a shadowing effect. It was noted in section 4.2 that during the survey, a bulldozer had begun working in this area while the eBee was taking photographs. This is the most probable cause of the shadow.

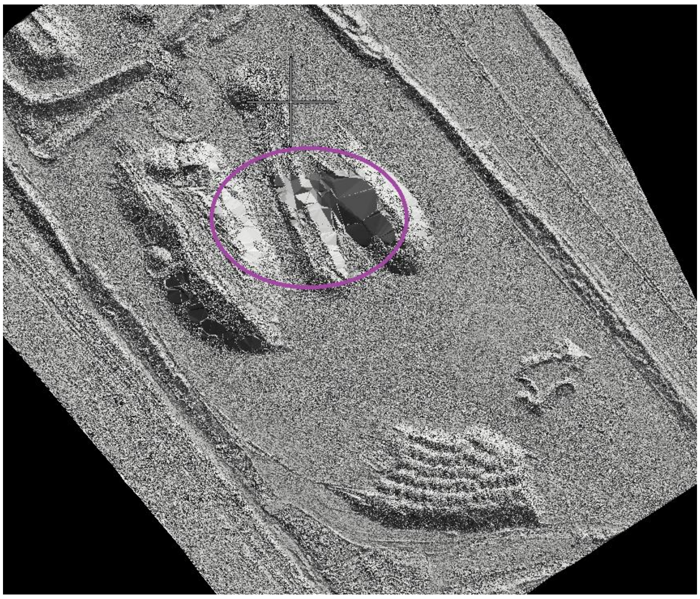


Figure 4.10: DTM produced using photographs collected from the eBee UAV.

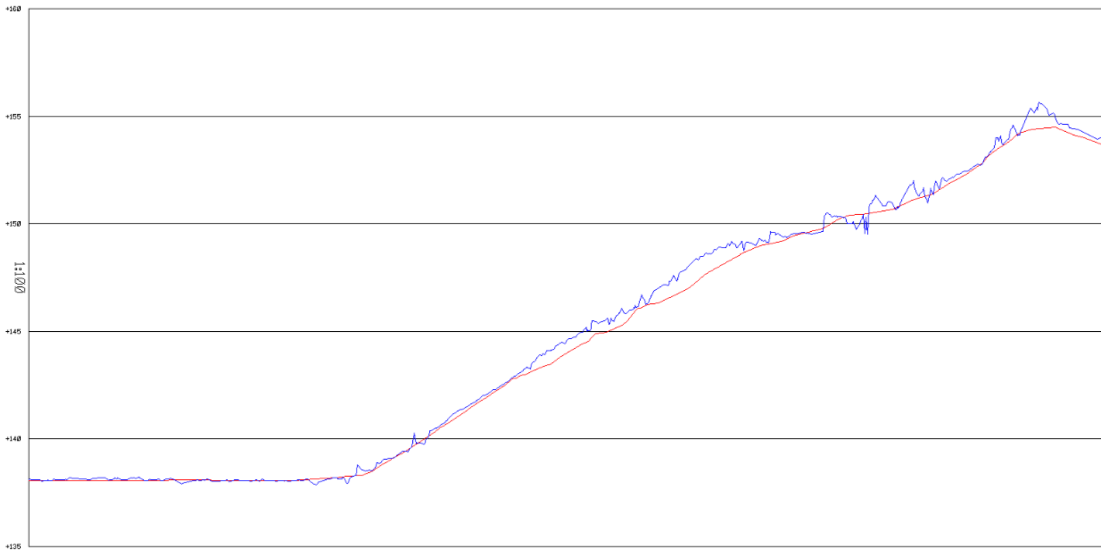


Figure 4.11: The red line represents the profile of SP1 picked up with the terrestrial laser scanner. The blue line represents the profile of SP1 generated with the eBee photographs. This demonstrates how “noisy” the UAS DTM is. It also reveals that this noise is most intense on the slope of the stockpile.

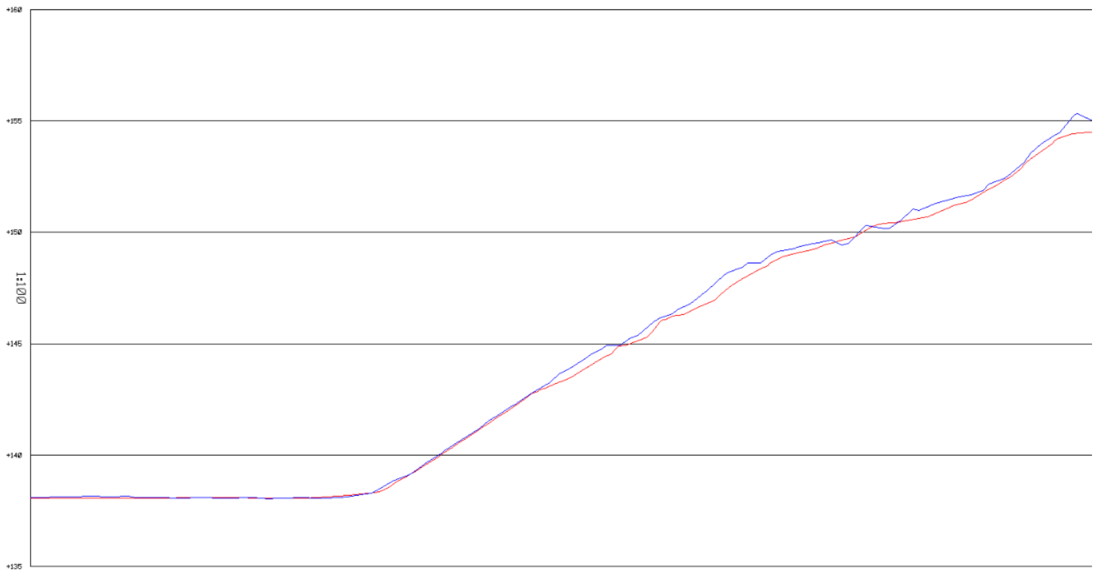


Figure 4.12: It can be seen that by reducing the point density of the UAS DTM, that noise has been significantly reduced. However, there is still less correlation on the slope of the stockpile, and unusual variations (i.e. noise) in the UAS DTM still occur.

The “fuzzy” appearance of the DTM is because of the highly dense point cloud (approximately 3.6cm point spacing). These results are similar to those in Walker and Willgoose (2006), which found that dense elevation models derived via photogrammetric heighting typically contain a high degree of noise (i.e. erroneous or unwanted points). Fig. 4.11 (previous page) is a cross section of SP1, and it can be seen that the UAV DTM has been poorly produced compared to the TLS DTM; which is smooth and gives a better representation of the actual surface. By reducing the point density of the point cloud the appearance of the eBee DTM can be improved (Walker & Willgoose 2006).

Thankfully this had already been done during the point-cloud generation process described in section 4.3.4. When producing the high-density point cloud, the photo processing software automatically generated a second point cloud with a point density of only 1 metre. This point cloud was filtered and modelled and compared to the TLS DTM. Fig. 4.12 (previous page) is a cross section showing that the newly generated surface is much smoother in appearance and more accurately defines the surface of the stockpile. As such, the 1x1m DTM has been used in the following analysis instead of the 3.6cm model.

4.3.6 The impact of “shadow”

Shadow presents a challenge for analyzing the quality of a DTM. Shadow is caused when there are “gaps” in the data, i.e. portions of the point cloud are missing. When these gaps are triangulated, modelling software will simply stretch 3D surfaces between opposing edges of the void (Fig. 4.13), creating a totally incorrect representation of the surface being modeled (Fig. 4.14).

In order to check a DTM, it is compared with accurately acquired check data (by determining the differences in height). However, if shadow areas are included in these comparisons then the results will be untrue, and the comparison will be incorrect for the reasons explained above.

It should be remembered that shadow areas are not the result of "bad measurements"; if this was the case then they, in fact, should be included in the comparison because they were physical measurements recorded by the instrument. However, "shadow" is simply the result of *no data* existing in a particular area because of, for example, an inability to access that area (i.e. no access to the top of coal stockpiles) or interference from another object (i.e. a bulldozer working on top of the stockpiles).

In order for the comparisons to be accurate, these shadow areas must be excluded from the comparison of the two DTMs.

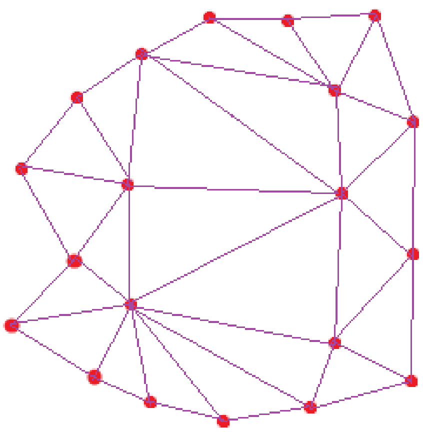


Figure 4.13: The red dots represent 3D points collected during a survey. Triangulation occurs between each of the 3D points. Notice the elongated triangles in the middle of the diagram where there is missing data, i.e. "shadow".

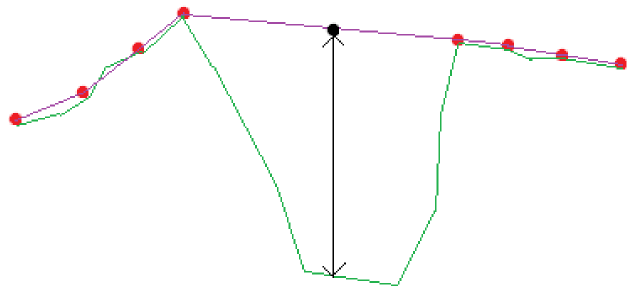


Figure 4.14: Again the red dots represent 3D points and the purple line represents the triangulated surface. The green line represents natural surface. If someone were to use this triangulated surface to measure a height (black dot) then the information could be incorrect by a substantial amount.

4.4 Preparing the data for analysis

Although the DTMs have been generated, it is still not possible to complete an analysis and compare the differences between them. In order for the analysis of the external quality to take place (as explained in section 2.8), surface heights must be sampled and portions of the DTM must be excluded (i.e. shadow areas).

4.4.1 Sampling of surface heights

The accuracy of the coal stockpile volume is primarily dependent on the vertical accuracy of the DTM. To determine the vertical accuracy, heights from each surface must be sampled, compared and analysed. Some software packages are capable of performing this analysis at the press of a button, while others may only determine the volume between two surfaces, without providing detailed statistics on their correlation.

For this analysis, a 1x1 metre grid was generated over each surface using the same horizontal origin (i.e. corresponding points on both grids had the same horizontal coordinates) as shown in Fig. 4.15. The result is two sets of 3D coordinates; one for each surface with matching horizontal coordinates, but with different heights as shown in Fig. 4.16. However, as mentioned earlier, the shadowed areas of the DTMs must be excluded from this sampling.

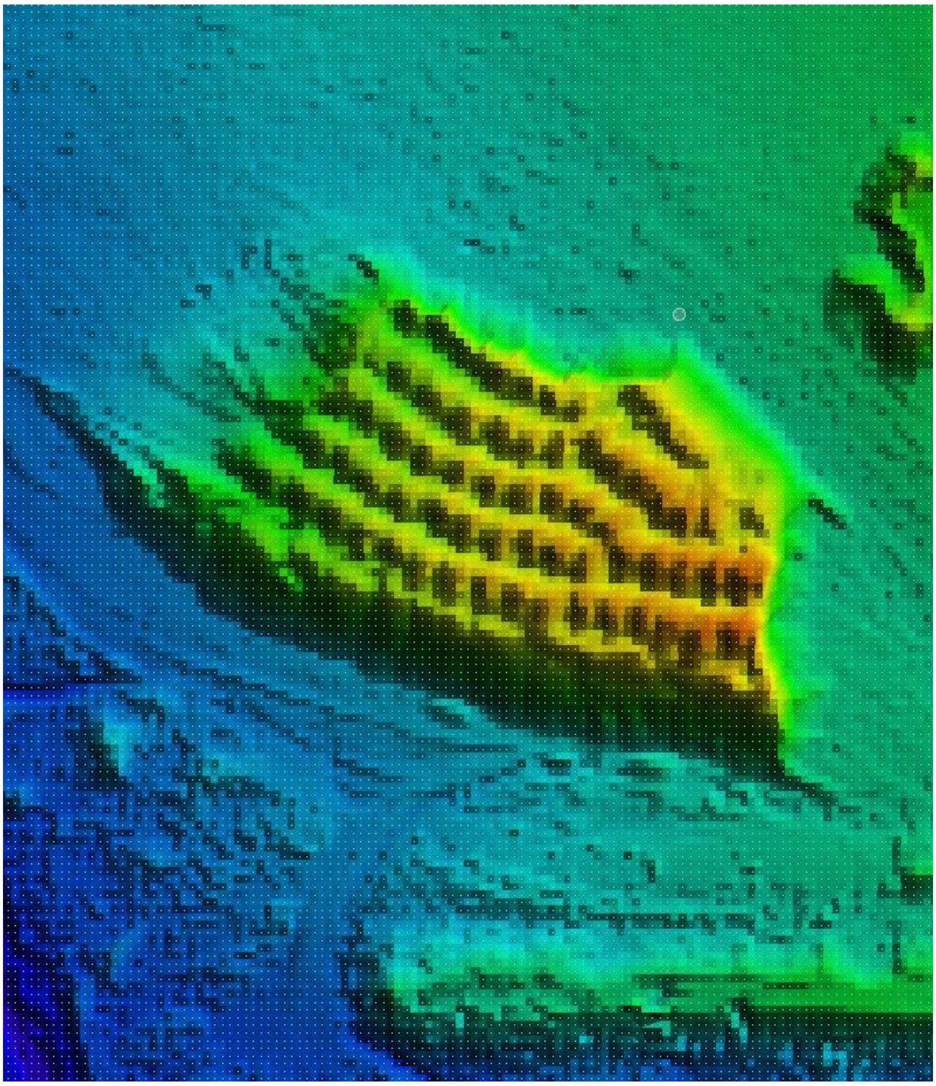


Figure 4.15: The image above displays a 1x1 metre grid (white points) generated over the surface of the UAV DTM.

Laser scanning DTM grid			UAV DTM grid		
Easting	**Northing**	**RL**	**Easting**	**Northing**	**RL**
696134	7419737	137.5444	696134	7419737	137.4151
696134	7419738	137.4472	696134	7419738	137.4099
696135	7419734	137.3675	696135	7419734	137.4094
696135	7419735	137.3732	696135	7419735	137.3845
696135	7419736	137.454	696135	7419736	137.3758
696135	7419737	137.4408	696135	7419737	137.4444
696135	7419738	137.372	696135	7419738	137.3948
696135	7419739	137.3816	696135	7419739	137.4004
696136	7419732	137.2949	696136	7419732	137.3644

Figure 4.16: A portion of the height samples taken from each DTM in metres.

4.4.2 Removing shaded areas from samples

To remove the shadowed areas from the samples, boundaries were created around the shadow on each DTM using CAD software, as shown in Fig. 4.17. Using the DTM and point cloud together allowed shadow allowed these areas to be accurately defined. The boundaries were then used to eliminate the points which were generated over the shadowed areas, as shown in Fig 4.18.

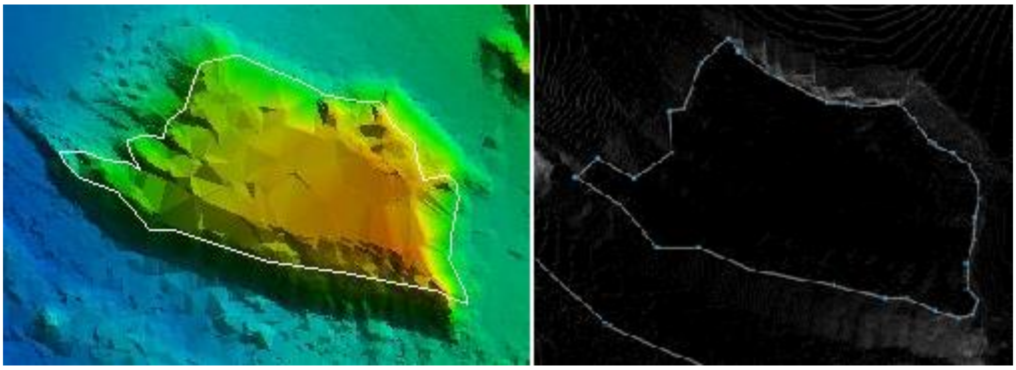


Figure 4.17: Boundaries were produced around shadowed areas using the DTMs and point clouds

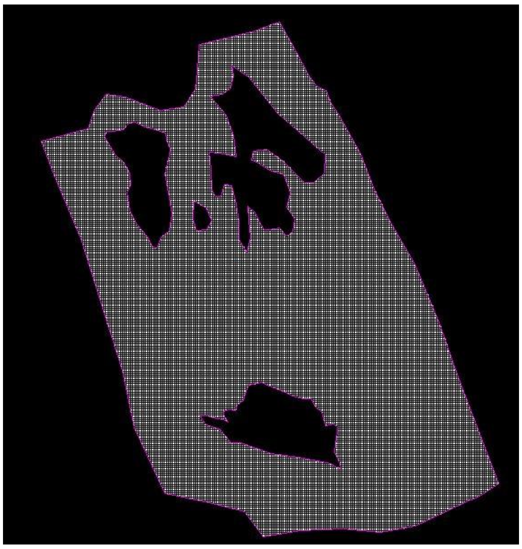


Figure 4.18: The boundaries were then used to eliminate the unwanted points from the sample grid.

4.5 Analysis of height residuals and volumes

4.5.1 Residuals of the whole stockpile area

As explained in section 2.8, the difference between accurate external check data (in this case, the terrestrial scans) and the subject DTM (UAV) will reveal the accuracy of the DTM (Karel, Pfeifer & Briese 2006). Jancso and Melykuti (2011) compared DTMs derived through different methods using visual comparisons and a statistical analysis of the residuals between each DTM. These statistics included:

- Minimum and maximum residual
- Range of the residuals
- Mean of the residuals
- Median residual
- Standard deviation

- Standard error

To calculate these statistics the residuals must first be determined. This is achieved by differencing the height of each corresponding horizontal coordinate, as shown in Fig. 4.19. Before calculating any statistics, the behavior of the data was checked by preparing a histogram of residual frequency, at a step of 0.005m (Graph 4.1). The bell-shape of the graph indicates that the data conforms to a normal distribution quite well.

X UAV	Y UAV	Z UAV	X Laser	Y Laser	Z Laser	ΔX	ΔY	ΔZ
696134	7419737	137.4151	696134	7419737	137.5444	0	0	-0.12927
696134	7419738	137.4099	696134	7419738	137.4472	0	0	-0.03734
696135	7419734	137.4094	696135	7419734	137.3675	0	0	0.04192
696135	7419735	137.3845	696135	7419735	137.3732	0	0	0.011345
696135	7419736	137.3758	696135	7419736	137.454	0	0	-0.0782
696135	7419737	137.4444	696135	7419737	137.4408	0	0	0.003576
696135	7419738	137.3948	696135	7419738	137.372	0	0	0.022787
696135	7419739	137.4004	696135	7419739	137.3816	0	0	0.018793
696136	7419732	137.3644	696136	7419732	137.2949	0	0	0.069509
696136	7419733	137.3345	696136	7419733	137.3064	0	0	0.028076
696136	7419734	137.3302	696136	7419734	137.3141	0	0	0.016081
696136	7419735	137.3601	696136	7419735	137.3198	0	0	0.040306
696136	7419736	137.3803	696136	7419736	137.3595	0	0	0.020832
696136	7419737	137.3806	696136	7419737	137.3679	0	0	0.012739
696136	7419738	137.4196	696136	7419738	137.3584	0	0	0.061233
696136	7419739	137.4303	696136	7419739	137.3751	0	0	0.055204
696136	7419740	137.4351	696136	7419740	137.3931	0	0	0.041978
696137	7419729	137.2557	696137	7419729	137.2442	0	0	0.011515
696137	7419730	137.3047	696137	7419730	137.2655	0	0	0.039231
696137	7419731	137.2901	696137	7419731	137.269	0	0	0.021092
696137	7419732	137.315	696137	7419732	137.2657	0	0	0.049287

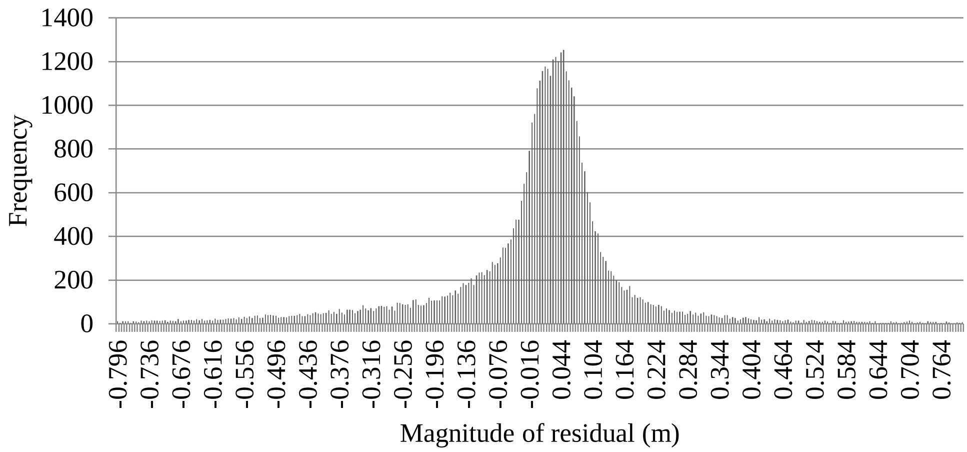
Figure 4.19: A sample of the height residuals used. The heights of each corresponding XY coordinate are differenced to obtain the residual (in metres). The X and Y coordinates provide a check that the correct grid points have been differenced from each other.

Having determined that the data conforms to a normal distribution, the primary statistics were calculated, as displayed in Table 4.3.

Graph 4.2 shows the normal distribution curve of the mean and standard deviation defined in Table 4.3.

These statistics show that accuracy appears to be good, with a mean value of only -0.012m. This means that the two DTMs only deviate, on average, by 12mm. However, a standard deviation of 0.338m indicates that precision is low. Also, a maximum and minimum residual of 3.507m and -3.796m respectively indicate that there are some significant variations present.

Graph 4.1: Historgram of Hieght Residual Frequency



Graph 4.2: Normal distribution of residuals

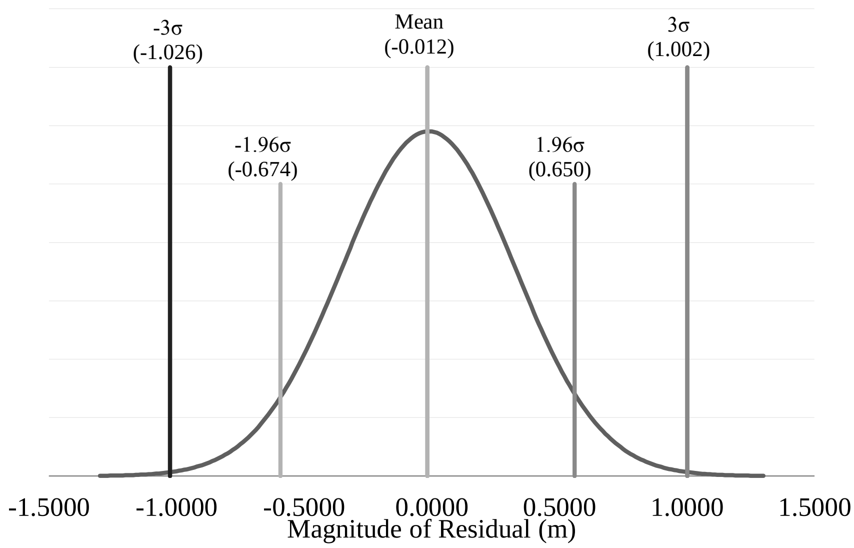


Table 4.3: Primary statistics of DTM A – DTM B.

Count	38637 points
Mean	-0.012m
Median	0.0310m
Max	3.507m
Min	-3.796m
Range	7.303m
St. Dev	0.338m

The statistics presented in Table 4.3 do not provide enough information to explain why such large variations are occurring. In addition to a statistical analysis, Jancso and Melykuti (2011) used a number of visual aids to demonstrate the variations between the two DTMs, including residual maps which proved to be a robust method of identifying areas where large residuals occur.

4.5.2 Visual interpretation

A residual map was plotted using the horizontal coordinates of each residual value. This map (Fig. 4.20) reveals the areas where the DTMs varied the most significantly. Note that the "holes" in the map represent areas where shadow was found in the original DTMs.

Immediately, the area surrounding Stockpile 2 (SP2) is suspect, where the variance map indicates there are deviations of over 3 metres. It was noted earlier that a bulldozer had been operating in this area which resulted in a large portion of shadow. It was assumed that the shadowed areas identified in section 4.3.5 were the only areas that the bulldozer had compromised, but it appears that its work has in fact affected the majority of the stockpile.

Otherwise, it can be seen that the residuals are relatively small over the flat areas of the stockpiles (less than 0.1m), but become greater (upwards of 2.0m) on the slopes of the stockpiles where the residual map can be seen to display shades of red and dark green.

After making these observations, the residuals on the slopes of the stockpiles were assessed individually to complete a more accurate analysis.

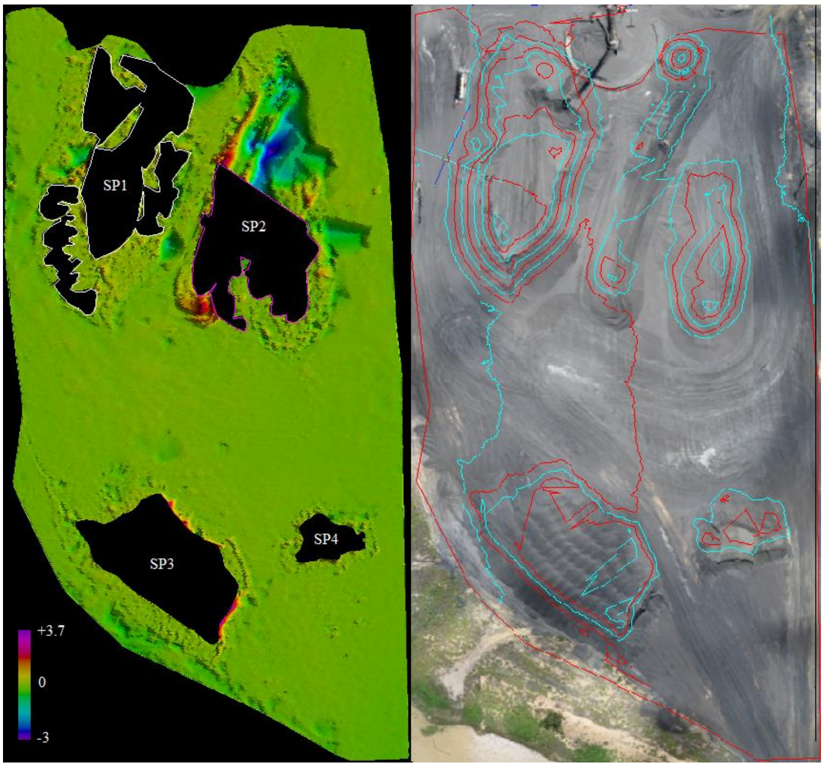


Figure 4.20: To the left is a residual map; the color scale indicates the magnitude of the residual in that location in metres. On the right, a photograph of the stockpile area overlaid with contours to provide some orientation and help to understand where the significant variations are occurring.

4.5.3 Sloped area and flat area residuals

To more accurately determine and compare the magnitude of the residuals at the slopes of the stockpiles, they were isolated and analysed separately. Tables 4.4 and 4.5 show the statistics of the residuals for the two larger stockpiles (SP1 and SP3). It can be seen that the two DTMs deviate further at the stockpiles (σ_{SP1}=0.256 and σ_{SP2}=0.256) than what they do at the flat areas of the stockpile area (σ_F=0.256, as seen in Table 4.6).

Again, residual plots were used to confirm the nature of the data (Graph 4.3, 4.4 and 4.5). For each, the bell-shaped appearance confirms that they are normally distributed. However, the histograms also show that for each stockpile, the residuals vary more aggressively than those for the flat surface. This reflects the "noisy" nature of the UAS DTM that was seen in section 4.3.5.

In each case there are a number of outliers. From the sample grid, 56 and 47 observations lie outside 3 standard deviations for SP1 and SP3 respectively, while 591 outliers exist for the flat surface. Surprisingly, although the mean and standard deviation for the flat surface is much better than those for the stockpiles, the proportion of outliers remain similar at approximately 2% (Table 4.7).

Table 4.4: Summary of residuals for SP1

Count	2509 points
Mean	0.140m
Median	0.15m
Max	2.538m
Min	1.391m
Range	3.929m
St. Dev (σ_{SP1})	0.256m

Table 4.5: Summary of residuals for SP3

Count	2340 points
Mean	0.116m
Median	0.073m
Max	3.507m
Min	-0.493m
Range	4m
St. Dev (σ_{SP2})	0.284m

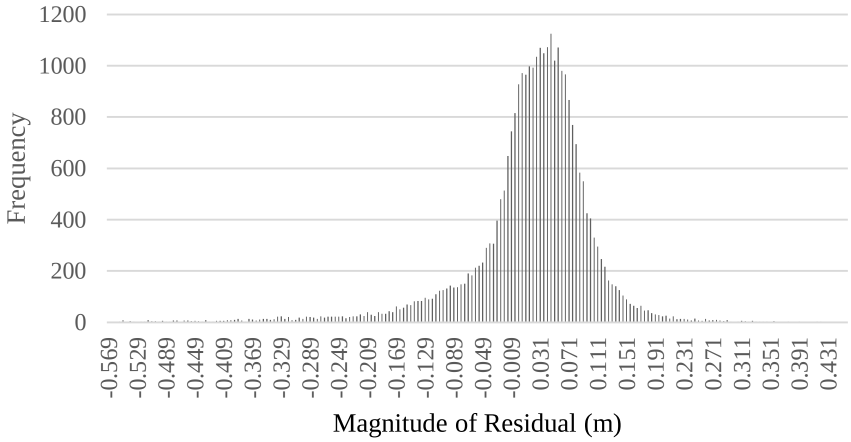
Table 4.6: Summary of residuals for flat terrain

Count	29965 points
Mean	0.012m
Median	0.027m
Max	1.106m
Min	-1.469m
Range	2.575m
St. Dev (σ_F)	0.107m

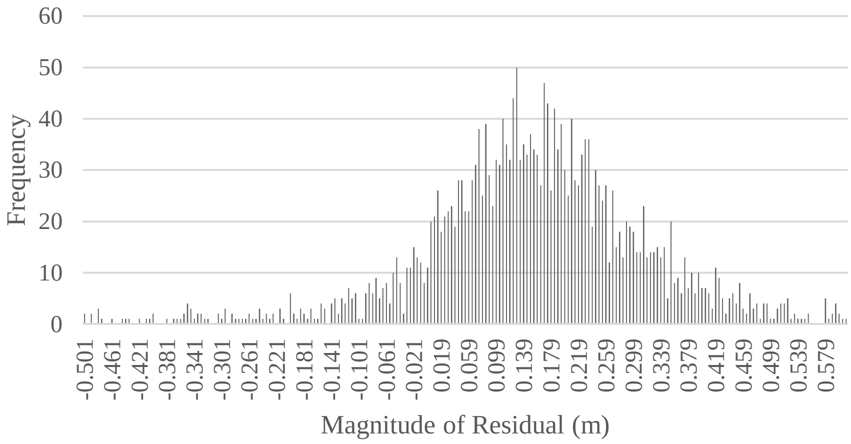
Table 4.7: Outliers (>3σ) in each surface

Surface	Number of samples	Outliers	Percentage
SP1	2509	56	2.2%
SP2	2340	47	2.0%
Flat Area	29965	591	1.9%

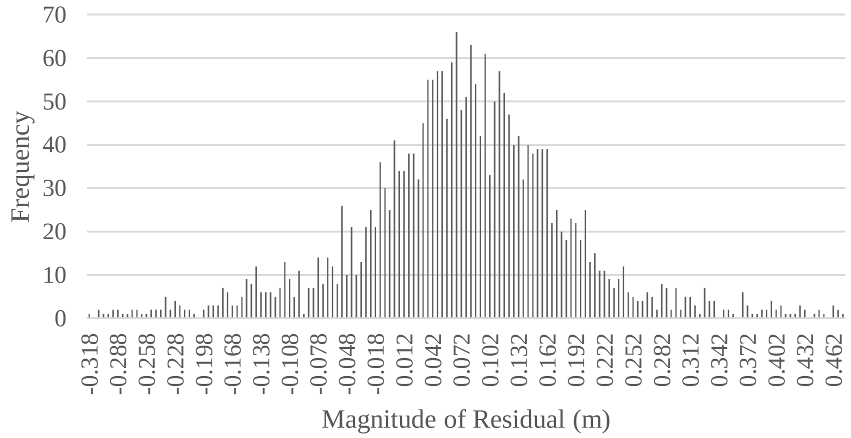
Graph 4.3: Histogram of Residuals for Flat Area



Graph 4.4: Historgram of Residuals for SP1



Graph 4.5: Histogram of Residuals for SP3



4.5.4 Volume differences

While considering the vertical accuracy of the DTM is important, the significance of the deviations described above should be determined by comparing the volumes calculated with each DTM. As explained in section 3.2.1, a volume difference of less than 2% is generally considered an adequate check.

Stockpile volumes are calculated using a "base" (or "lower") surface (i.e. a digital terrain model of the ground that the stockpile is resting on) and an "upper surface" (i.e. the model of the stockpile itself). With these two surfaces in hand, the prismoidal volume between the lower and upper triangulated surface can be easily determined using modelling software.

Screen captures of the volume calculations carried out for SP1 and SP3 using the eBee DTM and the TLS DTM may be seen in Appendix D; the resulting stockpile volumes are summarized in Table 4.8 below. These calculations reveal that there is no significant difference in volume, despite the shadow and the large variations in height across the two DTMs.

So, although the DTM deviates significantly in some areas, this does not mean that it cannot be used to determine coal stockpile volumes. The eBee has achieved the required level of volume accuracy (less than 2% difference), and can therefore be considered a suitable tool for performing this kind of survey.

Table 4.8: Volume differences

	TS DTM	**eBee DTM**	**Difference**	
SP1	40736.2m^3	41486.35m^3	-750.15m^3	*-1.84%*
SP3	19384.47m^3	19688.99m^3	-304.52m^3	*-1.57%*

4.6 Comments on efficiency, usability and legal responsibilities

4.6.1 Efficiency

Time logs kept during the course of the field and office work describe the duration of each survey (Table 4.9). These time logs finish at the point where a useable DTM has been produced. The duration of each survey was then used to determine the cost of the survey (Table 4.10), although knowing the cost of the survey is not necessary in this instance because both the TLS and the eBee require the same number of personnel, and there are no additional costs to consider. As such, sufficient comparisons can be made using the "time of survey".

Table 4.9: Time taken to complete work

	Field work (hours)	*Office work (hours)*	*Total (hours)*
UAV	1.38	8.06	9.44
TLS	2.65	1.52	4.17

Table 4.10: Cost of Survey

	Hours	*× Personnel*	*× Cost per hour ($)*	*= Cost ($)*	*+ Additional costs*	*= Total ($)*
UAV	9.44	1	85	802.4	0	802.4
TLS	2.65	1	85	225.3	0	225.3

At this point the eBee does not seem to provide any benefit, requiring approximately 3.6 times more time than the TLS to produce the DTM. However, the time logs indicate that the majority of this extra time is built up in the office simply processing data, as seen in Table 4.11.

Table 4.11: UAV office work

Activity	Time Taken (minutes)
Data transfer	10
Georectification	20
Initial processing	**100.8**
Point cloud densification	**122**
DEM generation	**210**
Point-cloud transfer	10
Point filter	10
Triangulation	1
Total (minutes)	483.8
Total (Hours)	8.06

Initial processing, point cloud densification and DEM generation have consumed the most time (approximately 7.21 hours). However, these processes require very little human input; they simply require someone to start the procedure, and then the computer must be allowed to process the data.

As such, while these processes are running, the surveyor can perform other work or make their time productive in some other way. Here the assumption is made that if the surveyor is not required to be at the computer for the full 7.21 hours of data processing, then that cost should not accumulate. Table 4.12 reveals the cost of survey after this has been taken into account.

Table 4.12: New cost of survey

	Hours	*× Personnel*	*× Cost per hour ($)*	*= Cost ($)*	*+ Additional cost*	*= Total ($)*
UAV	2.23	1	85	189.55	0	189.55
TLS	2.65	1	85	225.3	0	225.3

It can be seen that now the eBee competes well with the TLS in terms of efficiency.

4.6.2 Usability

The usability of the eBee is based on a comparison between the TLS and the UAV based on the System Usability Scale (SUS) by John Brooke (1986). More details on the SUS evaluation can be found in Appendix B. The SUS evaluates usability by measuring the user's responses to the following 10 statements:

1. I think I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

The SUS is a subjective evaluation of the ease-of-use, or usability. In order to guard against bias, the evaluation was carried out by a second person who was an observer of the survey, and has extended experience working with terrestrial laser scanners. The results of the evaluation were then averaged using the two responses.

The preliminary scores of the evaluation can be seen in Table 4.13. These scores were then reduced and placed on the SUS scale (Table 4.14), to yield a final score of 83.75 for the UAV, and 55 for the TLS.

Evidently the two respondents thought that the eBee provided a much better user experience compared to the terrestrial laser scanner. In their justification (Appendix C) the respondents considered a number of the physical characteristics and features outlined in section 2.3. The most significant considerations were:

- The manual labor required to operate each device.
    - The UAS requires very little physical effort to obtain results. It is light and does not require repeated setups. On the other hand, the TLS requires a lot of manual handling to setup and use, which also introduces a higher risk of equipment damage and personal injury.
- The intuitiveness of the software interface.
    - Thanks to the software, preparing flight plans with the eBee is a very basic process that does not require a large degree of technical knowledge or experience. The TLS on the other hand is less intuitive and an inexperienced operator is at risk of using the incorrect settings or not performing a required task; such as fine-scanning the backsight target or setting the correct scan parameters.
- Reduced risk to the operator.
    - The operator does not need to enter the coal stockpile area while the UAS is operating—they can stay well out of harm's way while it flies over the stockpiles. But to scan the stockpiles with a TLS, the operator needs to enter the stockpile area and, in some instances, come very close to machinery and plant which introduces a significant risk.
- Confidence in the data.
    - This is where the eBee is at disadvantage. The TLS provides more confidence in the quality of the results because the operator is able to check the data after each scan to ensure its completeness. The eBee however, does not provide this functionality. The photographs must be downloaded and pre-processed before any quality checks are provided. This means the

operator does not know if the photos are of sufficient quality, or if geo-tagging has been done correctly, until the survey is over and the day is potentially lost.

Table 4.13: Responses to the SUS survey

	Respondent 1		Respondent 2	
	UAV	**TLS**	**UAV**	**TLS**
Q1	*5*	*3*	*5*	*3*
Q2	*1*	*3*	*1*	*2*
Q3	*5*	*2*	*5*	*3*
Q4	*2*	*2*	*2*	*2*
Q5	*3*	*4*	*3*	*4*
Q6	*1*	*2*	*1*	*2*
Q7	*5*	*1*	*5*	*3*
Q8	*1*	*4*	*2*	*3*
Q9	*3*	*4*	*3*	*4*
Q10	*2*	*4*	*2*	*3*

Table 4.14: Reduced SUS scores

	Respondent 1		Respondent 2	
	UAV	**TLS**	**UAV**	**TLS**
Q1	*4*	*2*	*4*	*2*
Q2	*4*	*2*	*4*	*3*
Q3	*4*	*1*	*4*	*2*
Q4	*3*	*3*	*3*	*3*
Q5	*2*	*3*	*2*	*3*
Q6	*4*	*3*	*4*	*3*
Q7	*4*	*0*	*4*	*2*
Q8	*4*	*1*	*3*	*2*
Q9	*2*	*3*	*2*	*3*
Q10	*3*	*1*	*3*	*2*
Sum	*34*	*19*	*33*	*25*
***22.5**	*85*	*47.5*	*82.5*	*62.5*

Mean score UAV:	83.75
Mean score TLS:	55

4.6.3 Legal requirements

Using the assessment table from section 2.6, the main legal requirements for performing coal stockpile surveys with the eBee can be defined (Table 4.15). Because a mine site is not regarded as a populous area and the eBee is not operating beyond a visual line of site, no special permits are required. The operator only needs to be supervised by a certified operator and have a controller's certificate. Again, it is important to note that the costs noted in this table may vary significantly depending on the method of study; the training tools used; the effort placed into studying for the exams and so forth.

Table 4.15: Minimum CASR requirements for UAV coal stockpile survey

Category	**Application requirement**		**CASR Condition**	**Outcome**
Who will operate the UAV?	1. Does an employee of the organisation possess a Controller's Certificate?	Yes →	Proceed to the Operator's Certificate.	No cost for controller certificate.
		No →	An employee will be required to obtain a controller's certificate.	+ $865 to $2875 to the cost of certification (worst case).
	2. Does a manager in the organisation possess an Operator's Certificate?	Yes →	Anyone in the organisation with a Controller's Certificate can operate the UAV.	No cost for operator.
		No →	The manager/an employee will need to obtain an Operator's Certificate.	+ $7200-$8000 to cost of certification (worst case scenario).
Where will the UAV be operated?	1. In a populous area (i.e. a city, town, or other area with a high population density)?	Yes →	You will require a certificate of airworthiness from CASA.	Varies depending on the circumstances.
		No →	UAV can operate below 400ft above ground level, outside of prohibited and restricted airspace.	UAV can operate.

	2. In prohibited or restricted airspace, or near an aerodrome?	Yes →	You will need to contact the authority controlling the airspace and obtain a permit.	Wait for permit to be issued.
		No →	UAV can operate below 400ft above ground level, outside of prohibited and restricted airspace.	UAV can operate.
Under what conditions will the UAS be operated in?	Under meteorological conditions with good visibility (i.e. clear weather during the day), and within a visible line of site?	Yes →	UAV can operate below 400ft above ground level, outside of prohibited and restricted airspace.	UAV can operate.
		No →	You must complete an Instrument Rating exam (IREX) and obtain a permit.	Completing an instrument rating exam requires a Private Pilot License. To prepare for an exam, a training course can be completed which may cost up to $1,400.

4.7 Summary

This chapter has described the results of a coal stockpile survey performed on the 18th of March, 2013 at Jellinbah Coal mine using a terrestrial laser scanner and an unmanned aerial vehicle (the "eBee"). The results have been compared and analysed, and have allowed a number of conclusions to be drawn about the accuracy, efficiency and usability of the eBee.

Some significant variations were discovered between the two DTMs, and a statistical analysis of the flat regions and steeply sloping regions revealed that the accuracy and precision of the DTM is good across the flat areas of the DTM, but low on the steep slopes of the stockpiles themselves. These anomalies will be discussed further in chapter 5.

However, by comparing volumes from each DTM it was concluded that these variations made no significant difference to the accuracy of the volume generated with the eBee DTM. This indicates that the eBee is suitable for use in this application.

However, accuracy is not the only consideration when it comes to selecting survey equipment. The analysis of volume accuracy is followed by a number of comments regarding efficiency and usability. These comments add additional points that need to be considered when evaluating the advantages and disadvantages of using the eBee for this particular type of survey.

Chapter 5 will now combine these results and discuss their significance. This discussion will use these results to accomplish the purpose of the evaluation outlined in section 2.6, and come to a final decision about using the eBee for coal stockpile surveys.

CHAPTER 5

Discussion and Recommendations

5.1 Using the eBee for surveying coal stockpile volumes

By following the evaluation plan outlined in section 2.6, the data which is necessary for making an informed decision about using the eBee for coal stockpile surveys has been acquired. Here, this data and its meaning is discussed.

The analysis of the vertical accuracy of the eBee DTM and the impact of these results is discussed first. This is followed by a discussion on the most likely sources of error and whether or not the results can be improved. This provides a different perspective on the project and shows the reader that improvements can be made.

This is followed by discussions on the efficiency and usability of the eBee, and the legal requirements for using it. Again, this provides some additional perspective on the meaning of the results, and enables the significance of these factors to be better understood.

After considering the meaning of each group of results separately, the significance of each of these factors is considered holistically. This enables the eBee's major benefits to be pinpointed, leading to a final recommendation about how coal stockpiles should be surveyed in the future.

5.1.1 Accuracy

In modern surveying, volumes are commonly computed using modelling software which uses two triangulation (or grid) surfaces to determine the volume between them as described in section 4.5.4. For stockpile calculations, these two surfaces are normally referred to as the base surface (i.e. the surface representing the ground that the stockpile is resting on) and the stockpile surface (Fig. 5.1a). The base surface is usually measured long before the coal stockpile is piled on top—and normally with a method that has good vertical accuracy, such as RTK GPS.

Fig. 5.1 also shows how erroneous height data may result in an incorrect stockpile volume. If the error over an entire stockpile was positive (i.e. RLs were measured to be greater than they really are), then the effect would be that the stockpile is incorrectly located above the base surface. This would result in additional, erroneous volume located between the base and the stockpile (Fig. 5.1c).

On the other hand, if the error over an entire stockpile was negative (i.e. RLs were measured to be lower than they really are), then the effect would be that the stockpile is incorrectly located beneath the base surface. This would result in a portion of the stockpile volume being excluded, because only the volume between the top (i.e. stockpile) surface and lower (i.e. base) surface is included in the calculation (Fig. 5.1b).

Table 5.1: Confidence intervals for SP1 and SP2

Stockpile	95% confidence interval		
SP1	-0.361m	$< \mu <$	0.640m
SP3	-0.445m	$< \mu <$	0.673m

As such, if the error such as that identified in the Chapter 4 (and described in Table 5.1) exists in the stockpile surface, then the volumes may be significantly over or underestimated. However, the vertical error would need to be constant over the entire surface in order to result in a significant error in volume. If the vertical error is truly random, then the resulting error in volume would theoretically cancel out across the whole surface.

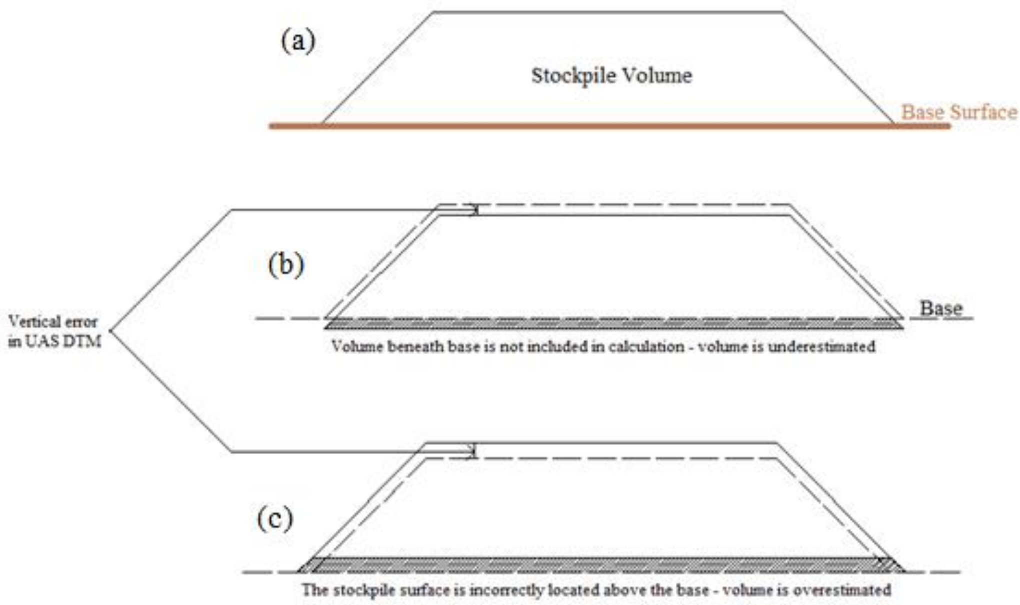


Figure 5.1: (a) How stockpile volumes are determined. (b) Volume is potentially underestimated by incorrect height data. (c) Volume is potentially overestimated by incorrect height data.

Chapter 4 revealed that the precision and the accuracy of the eBee DTM is relatively poor in some areas; such as on the slopes of the stockpiles. But the analysis also revealed that the vertical errors in the eBee DTM are (although at some points significant) mostly random, and the volume differences from section 4.5.4 reveal that they do not result in a significant difference in volume. Because the volumes were within tolerance, it is conclusive that the eBee is certainly a suitable tool for measuring coal stockpile volumes. This objective of the evaluation is satisfied.

5.1.2 Possible sources of error: can the results be improved?

The analysis in section 4.5 provided an insight into how the accuracy of the model generated using the eBee's photographs varies over different terrain types. It has been shown that on flat terrain, the accuracy and precision are quite good, with a 95% confidence interval of 12mm ±209mm. Although the accuracy is significantly worse on the steep slopes of the coal stockpiles where the 95% confidence interval exceeds ±0.5m. As described below, there are a number of reasons that could explain why this has occurred.

Poor planimetric accuracy

When comparing two DTMs, poor planimetric (horizontal) accuracy is an obvious and well known cause of vertical error on steep slopes (ASPRS Lidar Committee 2004; Hohle et al. n.d.). This is often referred to as "apparent vertical error", as it is not a true representation of vertical accuracy; it is merely the result of features being incorrectly positioned on the horizontal plane (Fig. 5.2).

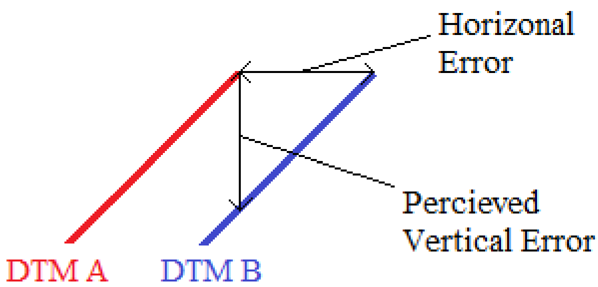


Figure 5.2: Even though there is no vertical error, the presence of horizontal error will exaggerate the vertical difference between two DTMs.

The question then becomes one of how significant the planimetric error was in the eBee and TLS DTM. The residual map and the histograms of residual frequencies from section 4.5 indicate that there are no real gross horizontal errors that require a block-shift in either DTM; any horizontal errors are likely to be random and uncontrollable.

But despite the possibility of random horizontal errors, the cross section of the DTMs (In chapter 4, Fig. 4.12) revealed that the eBee DTM was exceptionally noisy in the vertical plane, even after the point cloud had been filtered. As such, noise is likely the most significant contributor to vertical error.

Noise

Significant vertical errors can be caused by noise. In a general sense noise is caused by trees, machinery and other obstructive in the DTM. In section 4.3 it was explained how a point filter was used to eliminate this noise from the point clouds. Although the filter performed poorly in some areas, mistakes were easily rectified by manual reclassification. In any case, noise from vegetation or machinery is unlikely as there are very few sources of noise on the coal stockpiles; they are completely devoid of vegetation and other foreign objects.

However, despite extensive point filtering the profiles seen in section 4.3 (Fig. 4.14 and 4.15) show that the eBee DTM is still very noisy. The frequent sharp spikes and dips in the DTM indicate that this noise is probably the result of poor photo processing. That is, the software (Terra3D) failed to determine accurate heights for each of the pixels.

There are two things which could have affected the quality of the processing. Firstly; the quality of the input data and secondly; the processing parameters set in the software.

Photo processing: input data

In reality, photo processing could have been affected by any of those factors described in section 2.7. This includes photo resolution; camera calibration; angles between photographs etc. Most of these factors were accounted for during the planning phase of the survey, but it is very likely that the optimum parameters were not achieved.

Because the eBee is so light, the windy conditions experienced during the survey (approx. 40km/h) could have had a major impact on the quality of the photographs. There is a high possibility that the windy conditions pushed the eBee around so much that some of the photographs were affected by apparent image motion (i.e. blurry photographs). By being pushed off of the designated flight path the overlap will have been affected as well.

In section 2.7 it is explained that the optimum photographic overlap for photogrammetry is approximately 60%. However, due to the very high likelihood of platform movement, the eBee specifications recommend a minimum overlap of 70% (as explained in section 2.4.2) to ensure that at least 50% overlap is achieved on all photographs. Due to the windy conditions experienced during the survey, the equipment provider conducting the demo recommended that the overlap should be increased *again* to 80%.

If an overlap of 80% was achieved throughout the entire survey (unlikely because there was a large degree of platform movement) then this could be the source of the noise found in the eBee DTM. Similarly, if the eBee was disturbed by the wind so much that the overlap frequently exceeded 80%, or frequently became less than 60%, then this would have had an impact on the results. If the eBee could be flown in perfect conditions (i.e. no wind) using the optimum overlap (60%) then there is a good possibility that the results could be improved.

Photo processing: software parameters

In addition to the quality of the input data, the noise could have been magnified by low or failed pixel correlation and inaccurate parallax measurements.

Before a height value can be calculated for a point, the points have to be matched on overlapping photographs. The matching pixels can then be analysed, and parallax values can be calculated and a height can be derived. These processes are highly automated in modern digital photogrammetry. Most software packages use a process known as "dense image matching" for the pixel matching process. Such automated processes are becoming more prevalent and have proven to be much more accurate for processing photographs obtained with light UAS platforms (Kung et al. 2011). However, these processes do have their shortfalls.

The process essentially relies on the contrast between features and points in order to determine a match. The software will select a small area from a reference image, and then search overlapping images for an area that matches in terms of color intensity and brightness (Fig. 5.3) (Gallup, Frahm & Pollefeys 2010).

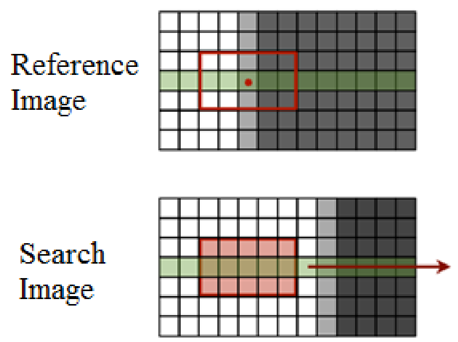


Figure 5.3: The dense-image matching process selects an area from the reference image (top) and searches for matching areas in the overlapping images (bottom).

The accuracy of this process is not only affected by the quality of the input data, but also by the number of corresponding grey/color values between the photographs—which is affected by the lighting and contrast of the photograph subject (Becker et al. 2006). If there is no contrast between the pixels, or the greyscale/color values are incorrect, then the process will be unable to find a suitable match for the reference area (Fig. 5.4).

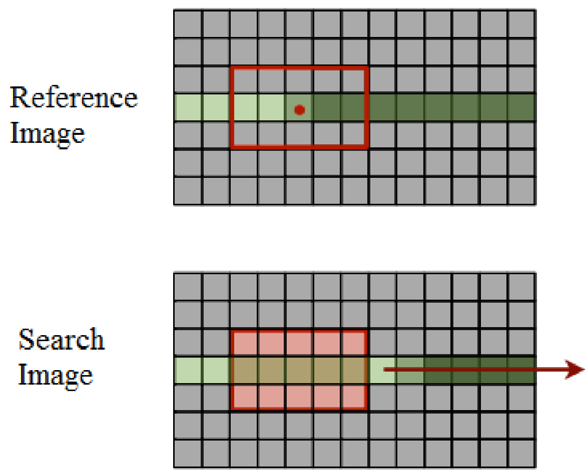


Figure 5.4: Limited contrast makes it difficult to accurately determine a matching area

Coal stockpiles are entirely black; poor contrast is a defining characteristic. As such there is the potential that the accuracy of the image matching processes is being affected by limited contrast. If this is the case then there is the possibility that the results can be improved by altering the image matching parameters.

There are two parameters that can be easily altered. The first is the scale of the search window. By increasing the scale, a larger reference area will be used and more pixels will be included in the search (Fig. 5.5). This increases the chance of a new feature or a change in contrast being included in the search window, which is useful in low-contrast areas or high-vegetation areas (i.e. forests, etc.) which would otherwise be difficult to match.

In reality this is actually increasing the tolerance of the matching process; it becomes easier for the software to find areas that correlate well together. However, higher correlation does not necessarily mean greater accuracy in this particular instance. Higher correlation only occurs because there is a larger area across which pixels are being match. Because of the increased volume of points, it is logical that the software will find more matches more frequently. This would actually increase the ambiguity in some of the results. The consequence of this is that the software will be less accurate when matching pixels that define a steep change in grade (i.e. the corner of a building or the toe of a stockpile).

So while there is the potential to enhance the processing by altering the size of the search window, it must be kept in mind that this bears some significant disadvantages as well.

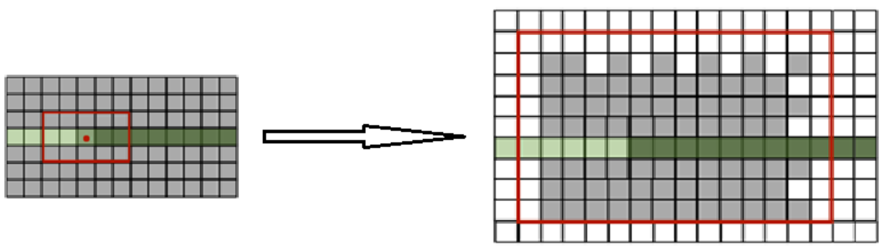


Figure 5.5: Increasing the search window includes more pixels in the image matching process.

The second parameter is the minimum number of pixel matches. The absolute minimum number of photographs that a pixel has to be matched in is obviously two (i.e. you need two images from two perspectives in order to measure parallax) (Fig. 5.6(a)). However, this minimum can be increased so that the software has to find more pixel matches before it accepts a point (Fig. 5.6(b)). It is possible to have 3 or even 4 pixel matches when high overlap is used with perpendicular flight lines. The advantage of this is that point accuracy is improved and noise is significantly reduced, because the 3D position of each point is confirmed using up to four pairs of photographs instead of only one.

The disadvantage is that the maximum point density that can be achieved in the point cloud is significantly reduced. The vast majority of points will only occur in two or maybe three photographs if perpendicular flight lines are used. If the minimum is set to 4 matches, this vast majority will be excluded from the point cloud.

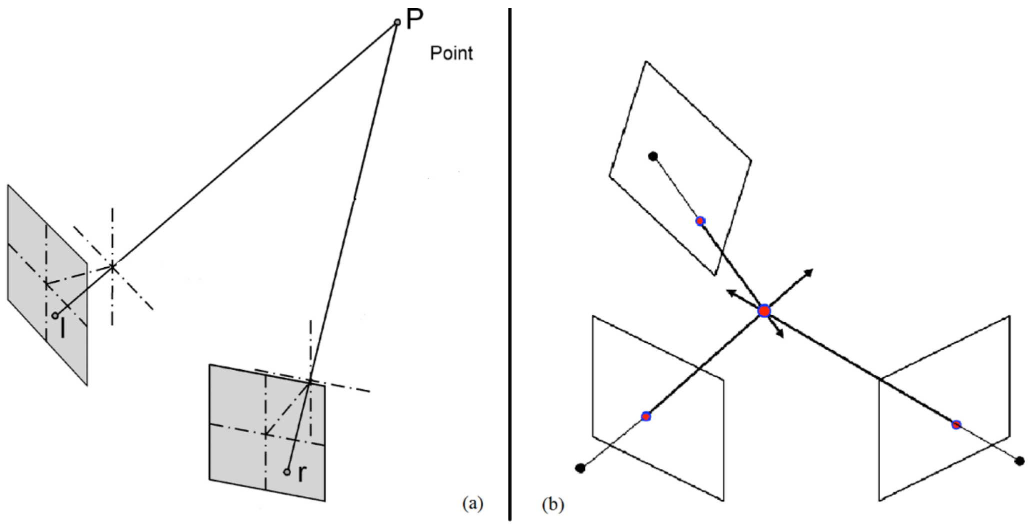


Figure 5.6: The minimum number of pixel matches can be increased so that more photographs are required before a 3D point is accepted; significantly reducing noise.

Accuracy can be improved

What this discussion has shown is that there may be ways to improve the accuracy of the eBee's output. This might be done by optimizing the photographic overlap and flying the eBee during more suitable weather conditions. It might also be improved by altering the processing parameters by increasing or decreasing the search window, and increasing the minimum number of pixel matches.

Due to time restrictions, these possibilities could not be investigated in this project. However it is a good possibility for future research.

5.1.3 Efficiency and Usability

Efficiency

The efficiency of the eBee was comparable with that of the VZ-1000 Terrestrial Laser Scanner (TLS) when generating a DTM of the coal stockpile area. However, this is based on the assumption that the surveyor could be productive in other ways while the photographs were being processed. Otherwise, processing of the photographs takes several hours longer than processing of the TLS data.

What this means in a practical sense is that the stockpile volumes might not be available until the following day, instead of the same afternoon. The significance of this may vary. Some surveyors may deem this difference in time to be trivial, while others may deem it significant.

In either case, it must be considered that the method used for determining efficiency in this project is limited. It does not reveal how the efficiency may change when the size or nature of the survey changes. For instance, the time it takes to survey a stockpile area with a terrestrial laser scanner (TLS) is entirely dependent on how many setups are required. A larger or more complex stockpile will require more setups and therefore more time with a terrestrial laser scanner; however the eBee will complete the survey in the same amount of time because it simply has to fly over it.

It might also be considered that processing time could be improved by using better hardware. However, this is ultimately a moot point. The processing time for the TLS data could also be improved with better hardware, albeit not by any significant margin as the processing time for the TLS data is already quite good.

So it can be said that for stockpile surveys of similar size or complexity; then the eBee does not appear to offer any significant advantages in terms of efficiency. However, for surveys of different sizes or complexity then this will most likely change.

Usability

Despite processing times being longer it was noted that the eBee had many significant advantages over the TLS in terms of usability and ease-of-use. Specifically, the eBee required very little manual labor to operate; was easy to operate with intuitive and easy-to-use software with a basic work-flow; and virtually eliminated all risk by removing any need for the operator to expose themselves to the hazards of the stockpile area.

Safety is a significant consideration not only for stockpile surveys, but for mine surveying in general. The hazards on a mine site are limitless, including heavy machinery; falling rocks; steep faces; open cavities and many more. Surveyors frequently place themselves at risk from these hazards in order to obtain the data they need. But using UAS such as the eBee completely eliminates the hazard by enabling surveyors to collect data in hazardous or inaccessible areas in the most remote way possible.

Although the lack of any quality assurance in the field is a concern with the UAS, it is slightly overcome by the “rapid processing” function of the Terra 3D software. This process takes only twenty minutes (instead of 1.5 hours for the full processing) and can be performed with a laptop in the field, providing a check on overlap and the quality of the ground control points. Although, it is still a disadvantage that the information cannot be verified as the survey progresses, as it can be with the TLS.

But the lack of quality assurance can also be overcome with adequate planning and good survey practice. Perpendicular flight lines should always be used when surveying with a UAS. When using perpendicular flight lines the area is essentially surveyed twice; providing a high level of photographic redundancy and avoiding the possibility of a bad photograph ruining the survey. Furthermore, placing more ground control points (GCPs) than what is minimally required (5 GCPs) will ensure sufficient redundancy of control so that the photographs can always be correctly georeferenced and checked.

Further considerations of the eBee's performance

Another significant consideration is the ability of the eBee to survey the top of the stockpiles without the surveyor needing to place himself in danger. The TLS is limited by a line of site from the ground—in most instances the tops of the stockpiles cannot be surveyed unless the surveyor can actually setup directly on the top. But on most active mines sites, this will not be possible due to limited accessibility due to the accompanying safety concerns.

But the eBee (and other UAS) offer an efficient and safe way to get around this problem. As seen in section 4.3, the DTM generated with the eBee had little to no shadow on top of the stockpiles. What shadow there was, was caused by interference from a bulldozer which can be easily prevented for future surveys.

One may also consider the aerial photographs as a benefit themselves. Having such an accurate visual record of the survey means there is no longer any doubt about what was surveyed and when.

5.1.4 Legal requirements

Only the minimum legal requirements for certification are required in order to perform a coal stockpile survey with a UAS. That is, Controller and Operator Certificates must be obtained from CASA as described in section 2.9. However, as shown, there is a significant time and money investment involved in obtaining these certificates, to be added onto the cost of the UAS itself.

The results of the analysis in section 4.5 have proven that the eBee can be used to perform stockpile surveys. Using the eBee, a DTM can be generated that produces volumes of sufficient accuracy. However, the results have also indicated that the eBee will not offer any remarkable increases in efficiency; although these results are limited; they are no longer reliable if the size or complexity of the survey changes.

The most significant justification for the cost and the time involved with getting setup and certified, can be found in the unquantified benefits of using the eBee. As discussed under section 5.2.1, these benefits include enhanced safety; reduced labor requirements; and no limits on accessibility. These benefits can be seen as significant—especially in a hazardous work environment such as a mine site. In these situations where both safety and accessibility are frequent issues, the benefits of the eBee easily justify the cost and the time involved with certification.

For contract surveyors who are not heavily involved in the mining industry, it must be remembered that only one application has been considered in this project (i.e. coal stockpile surveys). The cost and the time involved with setup and certification may be easily justified by a diverse business plan that uses the eBee for a wide variety of applications.

5.1.5 Final recommendation

The results and information that have been gathered and discussed indicate that there are no significant disadvantages when using the eBee. In fact, the eBee provides many significant benefits that make it a very practical tool for surveying coal stockpiles.

It can be used for determining the volume of a coal stockpile at a sufficient level of accuracy, while also significantly reducing the manual labor required to complete the task and eliminating almost all of the hazards involved. Considering these benefits, it is reasonable to use the eBee in place of a terrestrial laser scanner for surveying coal stockpiles.

The only disadvantage is the significant time and money investment that is required for setup and certification. There is enough justification provided by these results to conclude that certification is worth the time and the money. However, further justification can be derived by considering the other applications that the eBee is useful for and developing a business plan that makes full use of its benefits. Although, this is a task that is left to the professionals and businessmen who are managing the time and money.

5.2 Limitations of the evaluation

This section discusses how well the evaluation plan outlined in section 2.6 achieved the aims of the project. While this plan provided a suitable guide for collecting and anaylsing information about using a UAS for stockpile surveys, it is in many ways flawed and is in need of improvement. If an efficient and structured process for identifying the benefits of different UAS can be properly developed, then an evaluation based on the same premise as the one in this project could be of considerable benefit to the UAS industry.

5.2.1 How a similar evaluation can benefit the UAS industry

There is a need to evaluate the many different models of UAS individually, with consideration to the specific application they are intended to be used for. This is based on the fact that there are numerous models of UAS available, and each has different physical qualities and each has their own advantages and disadvantages which affect what the UAS can and cannot be used for.

Ideally this evaluation would establish what is positive about using that particular model of UAS in that specific application, and what is negative about it. It would identify what features or physical characteristics are beneficial, and those that are unnecessary or detrimental to their usefulness in surveying applications. This information could then be used by a variety of stakeholders to make informed decisions about the technology. This includes:

1. Surveyors and other professionals would have a robust understanding about what physical characteristics or features they need; the benefits that these features provide; and why and how much they need these benefits. This leads to faster and more confident decisions about using a UAS for survey work.
2. Distributors would have a better understanding about the benefits of using a UAS for a particular application. This would lead to better marketing, better support and more satisfied clients.
3. Manufacturers would have a better understanding of what their clients need; the features that are most important to their targeted industries; and what benefits surveyors and other professionals expect to derive from using a UAS. This leads to better designs, and by producing what the industry needs and wants; better sales.

5.2.2 What needs to be improved to obtain these benefits?

Accuracy

The first thing that should be considered is the assessment of accuracy. Accuracy is an important qualifier when it comes to using a UAS for survey work, but it is difficult to place into a systematic evaluation. Assessing accuracy requires specific technical knowledge, extensive experimental work and a detailed analysis. As explained in section 2.6 these characteristics alone make "accuracy" a highly unsuitable indicator in any evaluation; but it was included in this project because it is such an important consideration in most survey applications.

But, it is important to question whether or not it is really critical, or even necessary, to assess the accuracy of every model of UAS in every application. After all, the limitations of aerial photogrammetry are already established, and the applications that it is suitable for are already known. By evaluating the accuracy of a UAS, what is really being assessed or evaluated is the change in platform. The method of survey essentially remains the same.

For future evaluations it is sufficient to accept the accuracy of photogrammetry for what it has been shown to be in the past. Instead, greater focus should be applied to the platform itself and the different physical characteristics and features that improve or otherwise affect the performance of different types of UAS.

This means, we accept the accuracy of a UAS as what can generally be achieved by aerial photogrammetry. Instead, we focus on the different physical characteristics which guarantee that this accuracy will be achieved, for instance the wingspan and wind resistance which increases flight stability; the camera size and picture quality, and so on.

Efficiency

It has already been established that efficiency is an important consideration for businesses; greater efficiency means greater productivity, and a better cash flow. However, as discussed under section 5.1.3 the method used for measuring efficiency in this project is limited. It only considers a single scenario, and while this evaluation is aimed at only determining the benefits of using a UAS for a single specific application; it does not consider what happens to efficiency when the size or complexity of that application changes.

If efficiency is going to be included in an evaluation that is aimed at determining what a UAS should be used for, then the scope of that assessment needs to be broadened. It will need to include a variety of situations that may be experienced in day to day workings, i.e. different sized stockpile areas. However broadening the evaluation to this extent increases the complexity of the task so much that "efficiency" becomes as difficult to evaluate as accuracy.

At this point it should again be questioned whether or not it is important to assess efficiency at all. Common sense would say that for very large and complex areas, it will be far more efficient to fly over it than it would be to scan it with a laser scanner or survey it with GNSS. A more important consideration then is how much area the UAS can actually survey. This is a specification that falls under the "physical characteristics and features" of a UAS (i.e. battery life), a term that that has been used many times throughout this dissertation, and addressed specifically under section 2.3.

When considering the range of a UAS, legal regulations also come into consideration with the "visual line of site" restriction on UAS operations imposed by the Civil Aviation Safety Regulations.

Usability

The "System Usability Scale" provided a systematic way of assessing and comparing the ease-of-use (or "user friendliness") of the UAS. In many ways, the satisfaction of the user is important for obtaining some of the benefits described in section 5.2.1, as it provides feedback to other stakeholders about what the system is like to use—if it is actually better or worse than the current method of survey. However, it lacks the objectivity and repeatability that is necessary to draw constructive, scientific and useful conclusions.

One way of doing this is by categorizing the physical characteristics and features of modern UAS, and defining their advantages and disadvantages, similar to what has been done in section 2.3. Then, an evaluator can determine if a particular model of UAS is suitable for a particular application by defining the specific requirements of that application, and then identifying the physical characteristics and features of the UAS that are essential to achieving those requirements.

For instance, as mentioned earlier, one feature of a UAS is its endurance or maximum coverage area, i.e. how much area can be surveyed by the UAS in a single flight. The maximum area that needs to be surveyed can be compared to the maximum coverage area of the UAS to determine if it meets that requirement. Such an approach will provide a much more objective evaluation of the UAS, and provide more accurate and meaningful results that can be used by a variety of stakeholders.

5.2.3 What can be retained from this project for the future?

Although there are a number of things that need to be improved in the evaluation technique, there are some elements that might be retained in a properly prepared systematic and objective evaluation.

One of those things is the subjective evaluation of usability, which should be retained and conducted in parallel with an objective evaluation as described above. An objective evaluation of usability will define whether or not a UAS can be used for a specific application; while a subjective evaluation such as the System Usability Scale can define if it is actually better or worse than the other methods of survey that are available. Although it is not necessary to use the System Usability Scale; a more suitable assessment or questionnaire can be developed.

The section on “legal requirements” should also be retained. Identifying the legal requirements may not be essential to derive those benefits outlined in section 5.2.1, but it is important for everyone to be aware of them. This will inform the evaluator on what needs to be accomplished before the UAS can actually be used in the desired application (i.e. the need for certification before commercial use), and will also make the evaluator aware of any restrictions that they need to consider.

For example, the visible line of site (VLOS) restriction will impact how surveys need to be planned and managed. If a large area needs to be surveyed, then additional staff need to be included in the job and positioned so that at least one staff member has the UAS in sight at all times.

5.3 Summary

The first half of this chapter is focused on discussing the results and reaching a conclusion about the using the eBee for coal stockpile surveys. The second half is focused on the method; the evaluation technique that was used to guide the project. This discussion points out the evaluation’s flaws and ways that it might be improved.

The data collected by the eBee has been shown to be suitable for surveying coal stockpiles, but it is also shown that there is a good possibility that the results can be improved by altering the survey method and processing parameters. The efficiency has been discussed, and although the results do not indicate any significant benefits in this area, it is noted that the method which has been used to determine efficiency is limited and difficult to consider indicative of the eBee's overall efficiency. Following this, the eBee's less quantifiable benefits, such as a safety and reduced labor are discussed and it is concluded that they are the most significant benefits. It is these benefits that will justify the cost and the time involved with getting setup and certified to use the eBee.

The need for an evaluation of UAS capabilities has been discussed, and the potential benefits have been recapped. It is explained that in order to confer these benefits a more systematic and objective evaluation is needed. As such, the evaluation technique used in this project is criticized and suggestions are made to improve it so that it can become more efficient, and provide more useful and accurate results in the future.

It is suggested that the assessment of accuracy and efficiency be removed, as reasonable assumptions can be made that eliminate the need for an in-depth study of these areas. In order to confer those benefits which have been discussed in section 5.2.1, it is more important for the evaluation to focus more on the advantages and disadvantages of the various physical characteristics and features of the different types of UAS, and how these impact what the UAS can be used for, similar to what has been done in section 2.3. This would be a continuation of the results gathered from this project; where it was concluded that the most significant benefits that can be derived from a UAS come from benefits of its actual design (i.e. reduced labor, enhanced safety and a simplified work flow).

CHAPTER 6

Conclusion

6.1 Review of the project objectives

Unmanned Aerial Systems (UAS) are quickly becoming a viable option for surveyors in many industries, but many of these surveyors have trouble defining exactly what they can be used for, and the benefits they offer over alternative methods such as terrestrial laser scanners.

This project set out to define these benefits, by recognizing the factors pertaining to their use and performance, and the advantages and disadvantages of a UAS in surveying applications. The maxim being, that these factors could then be used in an evaluation to determine if a UAS should be used for coal stockpile surveys in place of other methods. This was achieved by:

1. Carrying out a literature review that:
   i. recognized the primary applications of the various models of UAS that are available today; and,
   ii. determined the different physical characteristics and features that exists between different models of UAS that have an impact on how they can be used in surveying; and,
   iii. recognized the various factors that impact the performance of the UAS and the ways that these should be accounted for; and,
   iv. outlined the legal requirements for using a UAS for commercial applications.

2. Recognizing and describing the factors that may impact the decision to use a UAS, those being: accuracy; efficiency; usability; and the legal requirements.
3. Researching the principles of an effective evaluation and applying them to the development of an evaluation plan that considers accuracy, efficiency, usability and legal requirements, in order to determine the benefits of using the UAS in a specific application.
4. Planning and conducting the survey of a coal stockpile area using a UAS (the eBee) and a terrestrial laser scanner.
5. Using the evaluation plan outlined previously to evaluate the performance of the UAS, leading to a recommendation about how it should be used.

While the results satisfied the aim of the project (as discussed below), and led to a desirable recommendation for the eBee UAV, the discussion (Chapter 5) pointed out a number of ways that the project can be improved, and made a number of recommendations for evaluations in the future.

These conclusions and recommendations for future evaluations are just as important as the results outlined in Chapter 4, and have been included in the key outcomes discussed below. They contribute significantly to understanding how this research may be used in future projects to benefit our understanding of how UAS can be used effectively in surveying, and to benefit the growth of the UAS industry.

6.2 Results

It has been shown that the eBee can be used for coal stockpile surveys. But the most significant question is not can it be used, but should it be used in place of other methods? Of particular interest in this project was the terrestrial laser scanner, and it has been shown that the eBee has many significant advantages over this particular method.

Several stockpiles were surveyed with the eBee and their volumes were calculated and compared to those derived from a terrestrial laser scanner. Although some significant variations were identified between the digital terrain model (DTM) produced by the eBee and the DTM produced by the terrestrial laser scanner (TLS), volume differences of less than 2% indicate that this had no significant impact on volume accuracy.

The analysis of efficiency found that the eBee offered no remarkable increase in productivity by taking 3.6 times longer than the TLS to produce an output. However, it was later discussed that the method used in this project to evaluate efficiency is limited and does not consider changes in the size or complexity of the survey. Because of this limitation, it is difficult to place too much weight on this result.

It was also commented that compared to the TLS, the eBee is significantly easier to use. Most significantly; it has no limitations with regards to access—it can fly over inaccessible or hazardous work areas; it reduces the amount of manual labor required to complete the survey; and it eliminates many of the hazards involved. When it comes to comparing the eBee with the TLS, these are the most significant advantages and provide enough justification to use the eBee in place of the TLS for coal stockpile surveys.

Legal certification is a long and expensive process; it represents the most significant disadvantage when using a UAS. However, these requirements must be accepted if the benefits of using a UAS are ever to be fully capitlised on. Although it may be difficult for a professional or a businessman to justify the cost and the time involved when considering only one application (i.e. coal stockpile surveys), a diverse business plan that recognizes the broad range of applications that a UAS can be used for could easily provide that justification.

6.3 Key outcomes

It has been identified that a UAS provides some significant benefits when surveying coal stockpiles. But these benefits are not limited to this single application—they can be easily recognized in a variety of other jobs and industries. This includes other open cut mining activities such as pit reconciliations and monthly volumes. Other industries can benefit from UAS as well including civil earthmoving and quarries. Additionally, this project confirms that UAS have the potential to be used in a variety of other surveying applications including topographic surveys; watershed analysis; road location and many, many more.

But the growth the UAS industry relies on the users being able to understand and identify these benefits. They need to recognize that there are many different UAS available, and they need to be able to select one that suits their needs. This can be achieved with an evaluation framework that is systematic and objective, which focuses on the advantages and disadvantages of the different models of UAS that are available. This will enable surveyors and other professionals to define the benefits and the limitations of UAS for themselves, providing the necessary information to make confident and informed decisions about using them.

This project has provided some of the ground work for such an evaluation. The physical characteristics and features that are available in the wide variety of UAS today have been identified and can be used in more comprehensive evaluations in the future. The results of this project have led to the recommendation that accuracy and efficiency do not need to be a recurring factor in future evaluations, and it has described the major benefits that should be focused on when justifying the use of UAS. Additionally, the legal requirements that should be considered before using a UAS have been outlined, and their impact on the cost of the UAS has been discussed. These requirements will continue to be a significant factor in future evaluations.

6.4 Future Research

Based on the above outcomes, there are many opportunities for future research that can utilize the results of this project. Firstly, the evaluation technique can be reviewed and significantly improved as per the suggestions under section 5.2. As mentioned above, there is a need for an efficient, systematic and objective process to evaluate the advantages and disadvantages of the various types of UAS that now exists, and determine if they can meet the requirements of the various applications that they might be used for. It is possible to base such an evaluation on the "ground work" established in this project.

Or, the idea of an evaluative framework can be abandoned to more closely follow those suggestions outline in section 5.2.2. Instead, the idea of a categorization and classification system can be investigated. Further research can be carried out that investigates the various types of UAS that are available. Then, the different types of UAS, their physical characteristics, features and abilities can be used to create a categorization system (similar to what has been done in section 2.3).

This is followed by defining the various options that exist under each category. This leads to an understanding of the advantages and disadvantages of each option, with respect to different surveying applications. For instance, when surveying very large forestry areas, a larger, mechanically launched UAS will be better than a smaller hand-launched type because it provides greater coverage area. The size and launch style are the categories, and the "options" are large or small (as a generalized example), and hand launched or mechanically launched. Determining the advantages and disadvantages of each option can be done for numerous surveying applications or situations to create a comprehensive categorization system that can be used to determine which UAS suits which application best.

Logically, this type of research could be extended to include an investigation into the use of a weighting system that prioritizes different features, characteristics and abilities of a UAS depending on the application. For instance, one category or classification may be "safety features", while another may be "endurance and maximum coverage area". For surveys on a mine site, safety features might be considered more important than endurance, and would therefore be weighted higher for this application.

Using such a categorization system will remove the need for a surveyor to perform any kind of evaluation. They will simply be required to consider what they will be using the UAS for, and use the categorization system to determine the features that they need the most – leading to a more confident decision about using a specific type of UAS. This will support the growth of the UAS industry in Australia and prompt surveyors to accept the technology with greater ease.

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List of Appendices

APPENDIX A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	**PATRICK METCALFE**
TOPIC:	UAV applications for a small surveying business
SUPERVISORS:	Dr. Albert Chong
ENROLMENT:	ENG4111 – S1, 2013 ENG4112 – S2, 2013
PROJECT AIM:	This project aims to investigate the practicality of an unmanned aerial vehicle for survey related tasks, by comparing it with currently used equipment and processes, using well defined criteria aimed at assessing accuracy, efficiency, economy and overall useability.

PROGRAMME: Issue A, 13th March 2013

1. Research UAVs and any current uses of UAVs in the civil sector. Include useability factors (training/legislative requirements), potential for future development and any current recognition by professional and government bodies.
2. Design a procedure for the survey of an earth stockpile and, if possible, a coal stockpile with a UAV. Also document the currently used procedure for surveying stockpiles with a terrestrial laser scanner.
3. Perform the survey of the stockpiles with the UAV and the laser scanner, keeping a detailed time log for each survey method.
4. Design a data processing workflow for the UAV photographs aimed at generating a DTM and calculating the stockpile volumes. Also document the currently used procedure for processing the data from the laser scanner.
5. Execute the data processing procedures, keeping a time log of the processing for each survey method.
6. Compare the results of the data processing and provide a thorough analysis of the quality and accuracy of the DTMs generated with each survey method. Also compare the time logs of each survey method to provide a thorough analysis of the efficiency and economy of each survey method.
7. Define relevant limitations of the UAV and state if the UAV offers a more practical solution to survey tasks carried out in the region.

As time permits:

8. Optimise an automatic point filtering process for point clouds generated with UAV photographs.

AGREED:

Patrick Metcalfe (Student)	Approved (Supervisor)
13 / 03 / 2013	13 / 03 / 2013

APPENDIX B

System Usability Scale

SUS - A quick and dirty usability scale

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Abstract

Usability does not exist in any absolute sense; it can only be defined with reference to particular contexts. This, in turn, means that there are no absolute measures of usability, since, if the usability of an artefact is defined by the context in which that artefact is used, measures of usability must of necessity be defined by that context too. Despite this, there is a need for broad general measures which can be used to compare usability across a range of contexts. In addition, there is a need for "quick and dirty" methods to allow low cost assessments of usability in industrial systems evaluation. This chapter describes the System Usability Scale (SUS) a reliable, low-cost usability scale that can be used for global assessments of systems usability.

Usability and context

Usability is not a quality that exists in any real or absolute sense. Perhaps it can be best summed up as being a general quality of the ***appropriateness to a purpose*** of any particular artefact. This notion is neatly summed up by Terry Pratchett in his novel "Moving Pictures":

> " 'Well, at least he keeps himself fit,' said the Archchancellor nastily. 'Not like the rest of you fellows. I went into the Uncommon Room this morning and it was full of chaps snoring!'
> 'That would be the senior masters, Master,' said the Bursar. 'I would say they are supremely fit, myself.'
> '*Fit?* The Dean looks like a man who's swallered a bed!'
> 'Ah, but Master,' said the Bursar, smiling indulgently, 'the word "fit",as I understand it, means "appropriate to a purpose", and I would say that the body of the Dean is supremely appropriate to the purpose of sitting around all day and eating big heavy meals.' The Dean permitted himself a little smile. " (Pratchett, 1990)

In just the same way, the usability of any tool or system has to be viewed in terms of the context in which it is used, and its appropriateness to that context. With particular reference to information systems, this view of usability is reflected in the current draft international standard ISO 9241-11 and in the European Community ESPRIT project MUSiC (Measuring Usability of Systems in Context) (e.g., Bevan, Kirakowski and Maissel, 1991). In general, it is impossible to specify the usability of a system (i.e., its fitness for purpose) without first defining who are the intended users of the system, the tasks those users will perform with it, and the characteristics of the physical, organisational and social environment in which it will be used.

Since usability is itself a moveable feast, it follows that measures of usability must themselves be dependent on the way in which usability is defined. It is possible to talk of some general classes of usability measure; ISO 9241-11 suggests that measures of usability should cover

- effectiveness (the ability of users to complete tasks using the system, and the quality of the output of those tasks),
- efficiency (the level of resource consumed in performing tasks)
- satisfaction (users' subjective reactions to using the system).

However, the precise measures to be used within each of these classes of metric can vary widely. For example, measures of effectiveness are very obviously determined by the types of task that are carried out with the system; a measure of effectiveness of a word processing system might be the number of letters written, and whether the letters produced are free of spelling mistakes. If the system supports the task of controlling an industrial process producing chemicals, on the other hand, the measures of task completion and quality are obviously going to reflect that process.

A consequence of the context-specificity of usability and measures of usability is that it is very difficult to make comparisons of usability across different systems. Comparing usability of different systems intended for different purposes is a clear case of "comparing apples and oranges" and should be avoided wherever possible. It is also difficult and potentially misleading to generalise design features and experience across systems; for example, just because a particular design feature has proved to be very useful in making one system usable does not necessarily mean that it will do so for another system with a different group of users doing different tasks in other environments.

If there is an area in which it is possible to make more generalised assessments of usability, which could bear cross-system comparison, it is the area of subjective assessments of usability. Subjective measures of usability are usually obtained through the use of questionnaires and attitude scales, and examples exist of general attitude scales which are not specific to any particular system (for example, CUSI (Kirakowski and Corbett, 1988)).

Industrial usability evaluation

The demands of evaluating usability of systems within an industrial context mean that often it is neither cost-effective nor practical to perform a full-blown context analysis and selection of suitable metrics. Often, all that is needed is a general indication of the overall level of usability of a system compared to its competitors or its predecessors. Equally, when selecting metrics, it is often desirable to have measures which do not require vast effort and expense to collect and analyse data.

These sorts of considerations were very important when, while setting up a usability engineering programme for integrated office systems engineering with Digital Equipment Co. Ltd, a need was identified for a subjective usability measure. The measure had to be capable of being administered quickly and simply, but also had to be reliable enough to be used to make comparisons of user performance changes from version to version of a software product.

The need for simplicity and speed came from the evaluation methods being used; users from customer sites would either visit a human factors laboratory, or a travelling laboratory would be set up at the customer site. The users would then work through evaluation exercises lasting between 20 minutes and an hour, at the end of which a subjective measure of system usability would be collected. As can be imagined, after this period of time, users could be very frustrated, especially if they had encountered problems, since no assistance was given. If they were then presented with a long questionnaire, containing in excess of 25 questions it was very likely that they would not complete it and there would be insufficient data to assess subjective reactions to system usability.

SUS - the System Usability Scale

In response to these requirements, a simple usability scale was developed. The System Usability Scale (SUS) is a simple, ten-item scale giving a global view of subjective assessments of usability.

SUS is a *Likert scale*. It is often assumed that a Likert scale is simply one based on forced-choice questions, where a statement is made and the respondent then indicates the degree of agreement or disagreement with the statement on a 5 (or 7) point scale. However, the construction of a Likert scale is somewhat more subtle than this. Whilst Likert scales are presented in this form, the statements with which the respondent indicates agreement and disagreement have to be selected carefully.

The technique used for selecting items for a Likert scale is to identify examples of things which lead to extreme expressions of the attitude being captured. For instance, if one was interested in attitudes to crimes and misdemeanours, one might use serial murder and parking offences as examples of the extreme ends of the spectrum. When these examples have been selected, then a sample of respondents is asked to give ratings to these examples across a wide pool of potential questionnaire items. For instance, respondents might be asked to respond to statements such as "hanging's too good for them", or "I can imagine myself doing something like this".

Given a large pool of such statements, there will generally be some where there is a lot of agreement between respondents. In addition, some of these will be ones where the statements provoke extreme statements of agreement or disagreement among all respondents. It is these latter statements which one tries to identify for inclusion in a Likert scale, since, we would hope that, if we have selected suitable examples, there would be general agreement of extreme attitudes to them. Items where there is ambiguity are not good discriminators of attitudes. For instance, while one hopes that there would be a general, extreme disagreement that "hanging's too good" for those who perpetrate parking offences, there may well be less agreement about applying this statement to serial killers, since opinions differ widely about the ethics and efficacy of capital punishment.

SUS was constructed using this technique. A pool of 50 potential questionnaire items was assembled. Two examples of software systems were then selected (one a linguistic tool aimed at end users, the other a tool for systems programmers) on the basis of general agreement that one was "really easy to use" and one was almost impossible to use, even for highly technically skilled users. 20 people from the office systems engineering group, with occupations ranging from secretary through to systems programmer then rated both systems against all 50 potential questionnaire items on a 5 point scale ranging from "strongly agree" to "strongly disagree".

The items leading to the most extreme responses from the original pool were then selected. There were very close intercorrelations between all of the selected items (± 0.7 to ± 0.9). In addition, items were selected so that the common response to half of them was strong agreement, and to the other half, strong disagreement. This was done in order to prevent response biases caused by respondents not having to think about each statement; by alternating positive and negative items, the respondent has to read each statement and make an effort to think whether they agree or disagree with it.

The System Usability Scale is shown in the next section of this chapter. It can be seen that the selected statements actually cover a variety of aspects of system usability, such as the need for support, training, and complexity, and thus have a high level of face validity for measuring usability of a system.

System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Using SUS

The SU scale is generally used after the respondent has had an opportunity to use the system being evaluated, but before any debriefing or discussion takes place. Respondents should be asked to record their immediate response to each item, rather than thinking about items for a long time.

All items should be checked. If a respondent feels that they cannot respond to a particular item, they should mark the centre point of the scale.

Scoring SUS

SUS yields a single number representing a composite measure of the overall usability of the system being studied. Note that scores for individual items are not meaningful on their own.

To calculate the SUS score, first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1,3,5,7,and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU.

SUS scores have a range of 0 to 100.

The following section gives an example of a scored SU scale.

System Usability Scale

	Strongly disagree 1	2	3	4	Strongly agree 5	
1. I think that I would like to use this system frequently					▯	4
2. I found the system unnecessarily complex				▯		1
3. I thought the system was easy to use		▯				1
4. I think that I would need the support of a technical person to be able to use this system	▯					4
5. I found the various functions in this system were well integrated		▯				1
6. I thought there was too much inconsistency in this system			▯			2
7. I would imagine that most people would learn to use this system very quickly		▯				1
8. I found the system very cumbersome to use				▯		1
9. I felt very confident using the system					▯	4
10. I needed to learn a lot of things before I could get going with this system		▯				3

Total score = 22

SUS Score = 22 *22.5 = 55

Conclusion

SUS has proved to be a valuable evaluation tool, being robust and reliable. It correlates well with other subjectives measures of usability (eg., the general usability subscale of the SUMI inventory developed in the MUSiC project (Kirakowski, personal communication)). SUS has been made freely available for use in usability assessment, and has been used for a variety of research projects and industrial evaluations; the only prerequisite for its use is that any published report should acknowledge the source of the measure.

Acknowledgements

SUS was developed as part of the usability engineering programme in integrated office systems development at Digital Equipment Co Ltd., Reading, United Kingdom.

References

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Kirakowski, J and Corbett, M, 1988, Measuring User Satisfaction, in D M Jones and R Winder (Eds.) *People and Computers IV*. Cambridge: Cambridge University Press.

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APPENDIX C

Summary of Responses to SUS Questions

Question 1

Responses to: *I think that I would use this system regularly.*

Respondent 1

If it was proven that it could achieve the same results as the terrestrial laser scanner (TLS) in terms of accuracy, then I would use the eBee more regularly, because it seems to require less effort than the TLS. Specifically, the eBee requires significantly less labor to operate compared to the TLS, which required a new setup for each scan.

Table C1: Response 1 to SUS Evaluation: Question 1

	Strongly Disagree				Strongly Agree
eBee					X
TLS			X		
	1	2	3	4	5

Respondent 2

I would use the eBee more frequently than the TLS, mainly because it offers a safer way to survey coal stockpiles. Even for this survey (the one performed for the project), a bulldozer had begun operating on the stockpiles without even contacting the surveyors to make sure it was safe to do so. If the surveyors had been performing a survey with the TLS, this would have been a significant safety hazard. But, because we were using the eBee at the time, there were no surveyors near the stockpiles, so there was no hazard and no risk.

Table C2: Response 2 to SUS Evaluation: Question 1

	Strongly Disagree				Strongly Agree
eBee					X
TLS			X		
	1	2	3	4	5

Question 2

Responses to: *I found the system unnecessarily complex.*

Respondent 1

There is nothing especially complex about the operation of either system, however the planning software for the eBee seemed much more intuitive. Making a flight plan was not as complex as I thought it would be, even though I had never used it before. For example, understanding the relationship between flying height and photo resolution was made easy by the explanations provided by the software.

On the other hand, the RiSCAN interface requires some specialist knowledge in order to use correctly. For example, you need to understand the difference between a 50kHz scanning program and a 70kHz scanning program, and a you need to understand why you need to fine-scan tie points to coordinate them correctly.

Table C3: Response 1 to SUS Evaluation: Question 2

	Strongly Disagree				Strongly Agree
eBee	X				
TLS			X		
	1	2	3	4	5

Respondent 2

The eBee interface seems more intuitive, but considering that it is unlikely that anyone other than a surveyor or other trained professional will be handling a terrestrial laser scanner, it shouldn't be considered unnecessarily complex. The interface is suitable for what and who it is designed for.

Table C4: Response 2 to SUS Evaluation: Question 2

	Strongly Disagree				Strongly Agree
eBee	X				
TLS		X			
	1	2	3	4	5

Question 3

Responses to: *I thought that the system was easy to use.*

Respondent 1

The intuitive user interface and the minimal amount of physical labor required to complete the survey makes the eBee much easier to operate than the TLS.

Table C5: Response 1 to SUS Evaluation: Question 3

	Strongly Disagree				Strongly Agree
eBee					X
TLS		X			
	1	2	3	4	5

Respondent 2

The eBee seemed intuitive; the controller interface displayed a satellite image of the survey area, and the operator simply identified the area they needed to survey by drawing a box around it. Then, the operator simply selected the pixel resolution they needed and the rest was practically taken care of. The data processing was straight forward and the instructions were easy to follow.

On the other hand, although RiSCAN is not overly complex, the operator requires some technical knowledge to understand the settings. This includes field and office work. So although it should not be considered “unnecessarily complex”, it should definitely be considered easier to use.

Table C6: Response 2 to SUS Evaluation: Question 3

	Strongly Disagree				Strongly Agree
eBee					X
TLS			X		
	1	2	3	4	5

Question 4

Response to: *I think that I would need the support of a technical person to be able to use this system.*

Respondent 1

After receiving the correct training I would not need a technical officer for the general operation of either device. But like most survey equipment, if there was a technical fault or issue with the device I would not be able to repair either device myself; a specialist would be needed.

Table C7: Response 1 to SUS Evaluation: Question 4

	Strongly Disagree				Strongly Agree
eBee		X			
TLS		X			
	1	2	3	4	5

Respondent 2

After a single training lesson I believe I could use the eBee confidently by myself, without the need for any technical support.

Table C8: Response 2 to SUS Evaluation: Question 4

	Strongly Disagree				Strongly Agree
eBee		X			
TLS		X			
	1	2	3	4	5

Question 5

Responses to: *I found the various functions in this system were well integrated.*

Respondent 1

The TLS is operated using the same software that is used to process the data, so there was no need to change projects or convert data before processing. However, to process photographs from the eBee, a separate software package must be installed and the photos must be imported into a new project file, which takes a little more time. This would be the only inconvenient element of the entire system.

Table C9: Response 1 to SUS Evaluation: Question 5

	Strongly Disagree				Strongly Agree
eBee			X		
TLS				X	
	1	2	3	4	5

Respondent 2

When using the TLS, the data can be checked as you go using the laptop. The eBee does not possess this functionality. However, considering the shorter field time (it only takes 20-30 minutes to perform an aerial survey with the eBee) this is not a significant draw back—more of an inconvenience, because you need to download and process the data before leaving the field. The results can be checked using the "rapid processing" option at the end of the survey.

Table C10: Response 2 to SUS Evaluation: Question 5

	Strongly Disagree				Strongly Agree
eBee			X		
TLS				X	
	1	2	3	4	5

Question 6

Responses to: *I thought there was too much inconsistency in this system.*

Respondent 1

There is no real issue with inconsistency when surveying stockpiles with either the eBee or TLS. However, the inconvenience mentioned earlier, of needing two software packages to process the eBee's photographs, is a slight hindrance.

Table C11: Response 1 to SUS Evaluation: Question 6

	Strongly Disagree				Strongly Agree
eBee		X			
TLS	X				
	1	2	3	4	5

Respondent 2

As mentioned earlier, the ability to check the quality of the scans as you progress through the survey is an element in favor of the TLS.

Table C12: Response 2 to SUS Evaluation: Question 6

	Strongly Disagree				Strongly Agree
eBee		X			
TLS	X				
	1	2	3	4	5

Question 7

Responses to: *I would imagine that most people would learn to use this system very quickly.*

Respondent 1

The eBee software interface is very intuitive. It is much easier to learn compared to the TLS which requires precision and care when setting up, and a good level of technical knowledge when operating and processing the data.

Table C13: Response 1 to SUS Evaluation: Question 7

	Strongly Disagree				Strongly Agree
eBee					X
TLS	X				
	1	2	3	4	5

Respondent 2

The eBee is much simpler to use in terms of technical input, but again the user must be considered. The TLS might be difficult to use for people who have had limited experience remote sensing devices, but for a surveyor who has experience and technical knowledge, it is much easier to learn.

Table C14: Response 2 to SUS Evaluation: Question 7

	Strongly Disagree				Strongly Agree
eBee					X
TLS			X		
	1	2	3	4	5

Question 8

Responses to: *I found the system very cumbersome to use.*

Respondent 1

As mentioned earlier the TLS requires more physical input in setting up the tripod legs, attaching the scanner, attaching the power leads and data cables, and booting up the laptop—this must happen for each scan, and it can be quite cumbersome when there is a large number of scans needed to complete a survey. On the other hand, the operation of the eBee is fairly autonomous, requiring only a few settings to be determined by the operator. Once the eBee is launched, it requires no input from the operator whatsoever until it lands.

Table C15: Response 1 to SUS Evaluation: Question 8

	Strongly Disagree				Strongly Agree
eBee	X				
TLS				X	
	1	2	3	4	5

Respondent 2

It is true that the laser scanner is a lot clumsier than the eBee when you are using tripod legs—as it was done for this survey. However, there are different platforms and configurations that are available today that eliminate a lot of this clumsiness. For instance, laser scanners are frequently being mounted on top of light vehicles (four wheel drives) and earth moving equipment (such as front end loaders) these days which significantly reduces how cumbersome they are. The scanner can be operated from within the cabin of the vehicle without the need for repeated setups—simply drive to the new scan point and perform the scan. I believe that this should be a consideration here.

Table C16: Response 2 to SUS Evaluation: Question 8

	Strongly Disagree				Strongly Agree
eBee	X				
TLS			X		
	1	2	3	4	5

Question 9

Responses to: *I felt very confident using the system.*

Respondent 1

I think safety is a significant factor when it comes to confidence in a particular piece of equipment or machinery. For surveyors, the eBee places us well out of harm's way. Surveyors are not required to enter the stockpile area where machinery may be working, or other dangers may exist in order to perform a survey. And with regards to the safety of the eBee itself, the software provides information about the UAV's status, including survey progress, wind speeds and stability, and it comes equipped with a fail-safe procedure so that if a malfunction does occur, or if wind speeds get too high, it can land safely in an "emergency zone" indicated by the operator. Considering these things, I would feel more confident, and safer using the eBee in a mining situation than a TLS.

Table C17: Response 1 to SUS Evaluation: Question 9

	Strongly Disagree				Strongly Agree
eBee			X		
TLS				X	
	1	2	3	4	5

Respondent 2

While the operation of the TLS is inherently safe, you have to enter the stockpile area in order to perform the survey, which can expose the operator to a number of risks. However the eBee virtually eliminates all of the hazards involved with a stockpile survey which is a significant advantage and greatly increases the confidence of the surveyor when they take it out to do a job.

However, the fact that you are able to quickly check your results in the field after every scan is a big advantage, providing confidence in the results.

Table C18: Response 1 to SUS Evaluation: Question 9

	Strongly Disagree				Strongly Agree
eBee			X		
TLS				X	
	1	2	3	4	5

Question 10

Responses to: *I needed to learn a lot of things before I could get going with this system.*

Respondent 1

The operation of the eBee itself is basic and it seems like almost anyone can do it. Understanding how pixel resolution and overlap affects the results may require some background knowledge, but the software provides enough prompts, and enough explanation to guide anyone through the process of planning and aerial survey, and processing the data. Most people would be able to operate the eBee and navigate its software efficiently on the first attempt.

The same might be said for the TLS, because to start a scan the only thing that is truly required is a click of the "start scan" button. However, the software is not as intuitive as the eBee so the user may become "lost in the settings". There are many different settings that can be altered in RiScan and unless the operator has some experience or background knowledge, they will not understand what they mean. Additionally, they need to be able to setup a tripod, level the scanner precisely and attach the correct cables. Really this is quite basic but it takes practice to do it efficiently.

Table C19: Response 1 to SUS Evaluation: Question 10

	Strongly Disagree				Strongly Agree
eBee		X			
TLS				X	
	1	2	3	4	5

Respondent 2

The eBee's reduced labor requirements and the intuitive software that accompanies it team up to provide a very easy to use product. The software is essentially a point and click operation, especially during the data processing stage where almost all of the settings are automatically optimized. The software dialogue is more than sufficient to guide almost anyone through the process.

But when using the TLS, there is a lot more responsibility on the operator. It is entirely up to them to ensure that the correct settings have been input and that the correct process has been followed. As mentioned earlier there is nothing exceptionally complex and the system performs well, but compared to the eBee it can be considered difficult to use.

Table C20: Response 1 to SUS Evaluation: Question 10

	Strongly Disagree				Strongly Agree
eBee		X			
TLS			X		
	1	2	3	4	5

APPENDIX D

Volume Calculation Screen Captures

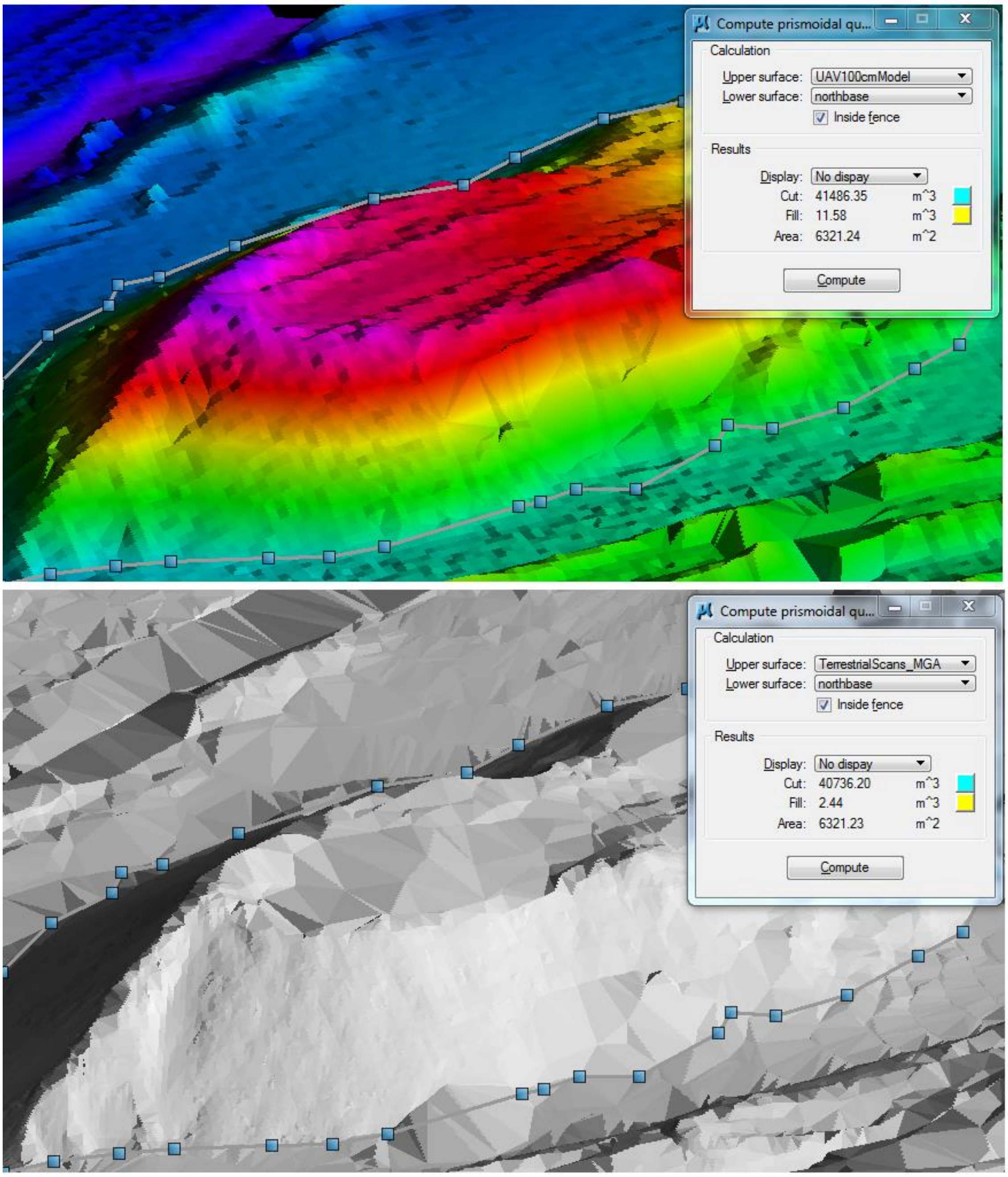


Figure D1: SP1 volume calculations using the eBee DTM (top) and the TS DTM (bottom).

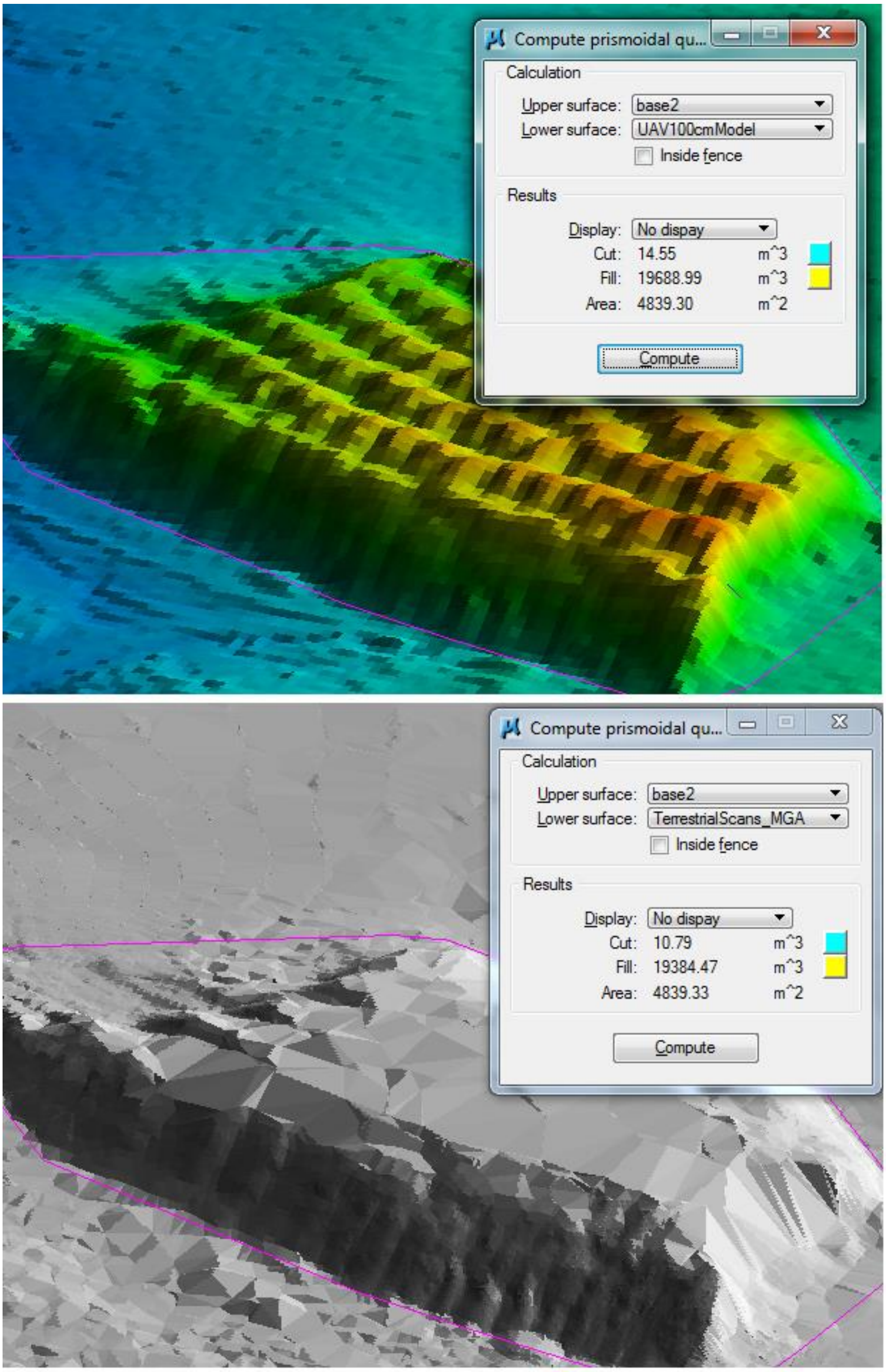


Figure D2: SP3 volume calculations using the eBee DTM (top) and the TS DTM (bottom).

APPENDIX E

eBee Datasheet

01 Choose the UAV for your application

sensesFly's ultra-lightweight UAVs are made out of flexible foam and include a high resolution camera. Discover which drone best suits your application.

02 Conduct your mission

All our UAVs are fully autonomous and ready-to-fly straight out of the box, allowing for hassle-free mission planning and easy operation within minutes.

03 Create maps and 3D models

Rapidly create geo-referenced orthomosaics and 3D models directly from the collected images using our Postflight software.

senseFly
A Parrot Company

senseFly Ltd
11, ch. de la Venoge
1024 Ecublens
Switzerland
www.sensefly.com

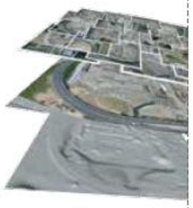
Carry-on luggage size

The **eBee** has a modular design, allowing the wings to be disassembled and stored with the central body and all its accessories in a small case. In fact the case is so small and lightweight that you can even take it as cabin baggage*. **The eBee will accompany you on all your projects.**

*IATA guidelines

Very easy to use

The **eBee** is lightweight enough to be launched by hand.
It is fully autonomous during its entire flight. When it comes to landing, the **eBee** can either land in a circular clearing or, when space is limited, use its advanced ground sensing technology to make a fully autonomous straight-line landing.
The included eMotion 2 software lets you plan, simulate, monitor and control the trajectory of the eBee both before and during flight. With simple drag&drop actions you can designate the area to be mapped, generate a flight plan and with a single mouse click you can update your mission or return the **eBee** to its starting location.



3D processing

With its 16MP high resolution camera, the **eBee** can capture images with a ground resolution of 3 to 30cm per pixel. Areas from 1.5 to 10km² can be mapped in a single flight depending on image resolution and flight altitude.
The **eBee** package includes Postflight Terra 3D (a fully automated 3D processing desktop software powered by Pix4D). After the initial data check in the field (overlap control and low resolution orthomosaic), **Terra 3D automatically creates a precise geo-referenced orthomosaic and digital elevation model (DEM).** Advanced users can further optimize their models through operator defined ground control points and seamlines.

Take your own aerial photos and produce precise orthomosaics and 3D models

- Surveying
- Mining
- Urban & Regional Planning
- Infrastructure Management
- Emergency and Disaster Management

96cm wingspan	
630g take-off weight	Up to 3km radio link
16MP camera, electronically integrated and controlled	Covers up to 1.5-10km²
	eMotion 2
Lithium polymer battery	Ground sensor and reverse engine technology for linear landing
45 minutes of flight time	
36-57km/h (10-16m/s) cruise speed	Postflight Terra 3D*
Up to 45km/h (12m/s) wind resistance	*powered by Pix4D

- **Very light:** Inherently harmless, easy take-off and landing
- **Optimized aerodynamic profile:** Maximum flight stability and endurance
- **Detachable wings:** Replaceable, very small packaging
- **Carry-on sized case (IATA guidelines):** Easy to transport, all in one box
- **Hand-launched:** No additional equipment needed
- **Intuitive planning, monitoring & control software:** Very easy to operate, minimal training required
- **Artificial Intelligence:** Takes off, flies and lands autonomously. No piloting skills needed
- **Automatic safety/emergency procedures:** Including wing detection, complete initial sensor check and in-flight hold&return button
- **Electric powered:** Low noise level, no pollution
- **Onboard data logging:** Easy image post-processing, direct interface to Terra 3D
- **Rapid data check & full 3D processing:** Automated processing of precise geo-referenced orthomosaics and 3D models. Quick data check in the field

APPENDIX F

VZ-1000 Datasheet

3D Terrestrial Laser Scanner with Online Waveform Processing

RIEGL VZ®-1000

- *very long range up to 1400 m*
- *high speed data acquisition*
- *wide field-of-view, configurable*
- *high-accuracy, high-precision ranging based on echo digitization and online waveform processing*
- *multiple target capability*
- *superior measurement capability in adverse atmospheric conditions*
- *high-precision mount for optional digital camera*
- *integrated inclination sensors and laser plummet*
- *integrated GPS receiver with antenna*
- *interface for external GNSS receiver*
- *various interfaces (LAN, WLAN, USB 2.0)*
- *internal data storage*

The *RIEGL* VZ-1000 V-Line® 3D Terrestrial Laser Scanner provides high speed, non-contact data acquisition using a narrow infrared laser beam and a fast scanning mechanism. High-accuracy laser ranging is based upon *RIEGL*'s unique echo digitization and online waveform processing, which enables superior measurement performance even during adverse environmental conditions and provides multiple return capability.

The *RIEGL* VZ-1000 is a very compact and lightweight surveying instrument, mountable in any orientation and able to perform in limited space conditions.

Modes of Operation

- stand-alone data acquisition without the need of a computer
- basic configuration and control via the built-in user interface
- remote operation via RISCAN PRO on a notebook, connected either via LAN interface or integrated WLAN
- well-documented command interface for smooth integration into mobile laser scanning systems
- interfacing to post processing software

User Interfaces

- Integrated Human-Machine Interface (HMI) for stand-alone operation without a computer
- high-resolution 3,5" TFT color display, 320 x 240 pixel, scratch resistant glass with anti-reflection coating and multi-lingual menu
- water and dirt resistant key pad with large buttons for instrument control
- speaker for audible status and operation communications

- *Topography & Mining*
- *As-Built Surveying*
- *Architecture & Facade Measurement*
- *Archaeology & Cultural Heritage Documentation*
- *City Modelling*
- *Civil Engineering*
- *Forestry*
- *Research*

visit our website
www.riegl.com

RIEGL®
LASER MEASUREMENT SYSTEMS

Terrestrial Laser Scanning

System Configuration

Scanner Hardware *RIEGL* VZ-1000
high-speed, high resolution and accurate 3D measurements

- *Range up to 1400 m @ Laser Class 1*
- *Repeatability 5 mm*
- *Measurement rate up to 122 000 measurements/sec*
- *Field of View up to 100° x 360°*
- *LAN/WLAN data interface, easily allowing wireless data transmission*
- *Operated by any standard PC or Notebook or cable less*
- *Fully portable, rugged & robust*

RiSCAN PRO Software
RIEGL software package for scanner operation and data processing

- *Data archiving using a well-documented tree structure in XML file format*
- *Object VIEW / INSPECTOR for intelligent data viewing and feature extraction*
- *Straightforward Global Registration*
- *Interfacing to Post Processing Software*

Digital Camera (optional)
provides high resolution calibrated color images

- *NIKON D800, D600*
  - *D800: 36.3 Megapixel, Nikon FX format*
  - *D600: 24.3 Megapixel, Nikon FX format*
  - *USB interface*

Mounting device with digital camera can be easily fixed by means of two knurled head screws. Precise position and orientation is provided by three supporting points. Power supply and USB 2.0 interface is provided by the scanner directly.

The combination of the key components <u>Scanner</u>, <u>Software</u> and <u>Camera</u> results in

- Automatic generation of high resolution textured meshes
- Photorealistic 3D reconstruction
- Exact identification of details
- Online position and distance measurements
- Online setting of any virtual point of view

Global Scan Position Registration

Stand-alone Registration

- *Integrated GPS receiver (L1)*
- *Integrated biaxial inclination sensors (tilt range ±10°, accuracy typ. ±0.008°)*
- *Integrated compass, accuracy typ. 1° (one sigma value, available for vertical scanner setup position)*
- *RiSCAN PRO Processing and Multistation Adjustment Module (MSA)*

Registration via control points

- *precise and fast fine scanning of retro-reflectors*
- *RiSCAN PRO Processing*

Totalstation-like-Registration

- *setup above well known point (integrated laser plummet)*
- *integrated inclination sensors*
- *precise fine scanning of well known remote target (reflector)*
- *RiSCAN PRO Processing Backsighting function*

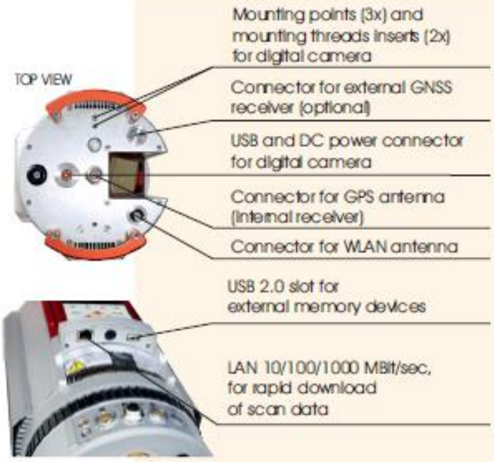
Operating Elements and Connectors

Communication and Interfaces

- *LAN port 10/100/1000 MBit/sec within rotating head*
- *LAN port 10/100 MBit/sec within base*
- *integrated WLAN interface with rod antenna*
- *USB 2.0 for external storage devices (USB flash drives, external HDD)*
- *USB 2.0 for connecting the optional digital camera*
- *connector for GPS antenna*
- *two ports for external power supply*
- *connector for external GPS synchronization pulse (1PPS)*
- *connector for external GNSS receiver*
- *connector for optional add-on battery*

Scan Data Storage

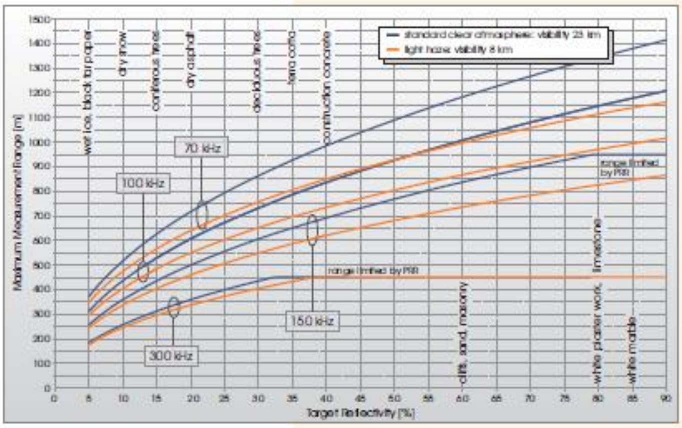
- *internal 32 GByte flash memory* *(1 GByte reserved for the operating system)*
- *external storage devices (USB flash drives or external hard drives) via USB 2.0 interface*



Max. Measurement Range

The following conditions are assumed:

Flat target larger than footprint of laser beam, perpendicular angle of incidence, average brightness



3

Technical Data 3D Scanner Hardware *RIEGL* VZ®-1000

Laser Product Classification — Class 1 Laser Product according to IEC60825-1:2007
The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated June 24, 2007.

CLASS 1 LASER PRODUCT

Range Performance[1]

Laser PRR (Peak)[2]	70 kHz	100 kHz	150 kHz	300 kHz
Effective Measurement Rate[2]	29 000 meas./sec.	42 000 meas./sec.	62 000 meas./sec.	122 000 meas./sec.
Max. Measurement Range[3] for natural targets $\rho \geq 90\%$ for natural targets $\rho \geq 20\%$	 1400 m 700 m	 1200 m 600 m	 950 m[4] 500 m	 450 m[4] 350 m
Max. Number of Targets per Pulse	practically unlimited[5]			
Accuracy[6][8]	8 mm			
Precision[7][8]	5 mm			

Minimum Range — 2.5 m
Laser Wavelength — near infrared
Beam Divergence[9] — 0.3 mrad

1) with online waveform processing
2) rounded values, selectable by measurement program
3) Typical values for average conditions. Maximum range is specified for flat targets with size in excess of the laser beam diameter, perpendicular angle of incidence, and for atmospheric visibility of 23 km. In bright sunlight, the max. range is shorter than under an overcast sky.
4) limited by PRR
5) details on request
6) Accuracy is the degree of conformity of a measured quantity to its actual (true) value.
7) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.
8) One sigma @ 100 m range under *RIEGL* test conditions.
9) Measured at the $1/e^2$ points. 0.3 mrad corresponds to an increase of 30 mm of beam diameter per 100 m distance.

Scan Performance

	Vertical (Line) Scan	Horizontal (Frame) Scan
Scan Angle Range	total 100° (+60° / -40°)	max. 360°
Scanning Mechanism	rotating multi-facet mirror	rotating head
Scan Speed	3 lines/sec to 120 lines/sec	0°/sec to 60°/sec[10]
Angular Stepwidth $\Delta\vartheta$ (vertical), $\Delta\varphi$ (horizontal)	$0.0024° \leq \Delta\vartheta \leq 0.288°$[11] between consecutive laser shots	$0.0024° \leq \Delta\varphi \leq 0.5°$[11] between consecutive scan lines
Angle Measurement Resolution	better 0.0005° (1.8 arcsec)	better 0.0005° (1.8 arcsec)

Inclination Sensors — integrated, for vertical scanner setup position, details see page 2
GPS receiver — integrated, L1 antenna
Compass — integrated, for vertical scanner setup position, details see page 2
Internal Sync Timer — integrated real-time synchronized time stamping of scan data
Scan Sync (optional) — scanner rotation synchronization

10) frame scan can be disabled, providing 2D operation
11) selectable, minimum stepwidth increasing to 0.004° @ 70 kHz PRR

General Technical Data

Power Supply Input Voltage — 11 - 32 V DC
Power Consumption — Scanning, typ. 82 W (max. 90 W)
External Power Supply — up to three independent external power sources can be connected for uninterrupted operation

Main Dimensions — ø 200 mm x 308 mm (diameter x length)
Weight — approx. 9.8 kg
Humidity — max. 80 % non condensing @ +31°C
Protection Class — IP 64 (dust and splash-proof)
Temperature Range
- Storage — -10°C to +50°C
- Operation — 0°C to +40°: standard operation
- Low Temperature Operation[12] — -20°C: continuous scanning operation if instrument is powered on while internal temperature is at or above 0°C and still air
  -40°C: scanning operation for about 20 minutes if instrument is powered on while internal temperature is at or above 15°C and still air

RIEGL® LASER MEASUREMENT SYSTEMS

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Data Sheet, *RIEGL* VZ-1000, 2013-09-18

APPENDIX G

R8 GNSS Receiver Datasheet

DATASHEET

TRIMBLE R8 GNSS SYSTEM

KEY FEATURES

Advanced satellite tracking with **Trimble 360 receiver technology**

Includes Trimble Maxwell 6 chips with **440 channels**

Unmatched GNSS tracking performance

Web user interface and remote configuration

Base and rover communications **options to suit any application**

THE INDUSTRY LEADING TOTAL GNSS SOLUTION

The Trimble® R8 GNSS system has long set the bar for advanced GNSS surveying systems. Through advanced Trimble 360 tracking technology and a comprehensive set of communication options integrated into a flexible system design, this integrated GNSS system delivers industry-leading performance. For surveyors facing demanding RTK applications, the Trimble R8 is an invaluable GNSS partner.

TRIMBLE 360 RECEIVER TECHNOLOGY

Future-proof your investment

Powerful Trimble 360 receiver technology integrated in the Trimble R8 supports signals from all existing and planned GNSS constellations and augmentation systems providing unmatched GNSS tracking performance. With this leading-edge technology, it is now possible for surveyors to expand the reach of their GNSS rovers into areas that were previously too obscured, such as under trees and in dense urban areas.

With two integrated Trimble Maxwell™ 6 chips, the Trimble R8 offers an unparalleled 440 GNSS channels. Also capable of tracking carrier signals from a wide range of satellite systems, including GPS, GLONASS, Galileo, BeiDou (COMPASS), and QZSS, the Trimble R8 provides a robust solution for surveyors.

The CMRx communications protocol in the Trimble R8 provides unprecedented correction compression for optimized bandwidth and full utilization all of the satellites in view, giving you the most reliable positioning performance.

Designed with the future in mind, Trimble 360 technology is optimized to receive future planned signals as the number of available satellites continues to grow. With Trimble 360 technology, the Trimble R8 delivers business confidence with a sound GNSS investment for today and long into the future.

FLEXIBLE SYSTEM DESIGN

The Trimble R8 combines the most comprehensive feature set into an integrated and flexible system design for demanding surveying applications. Connect directly to the controller, receive RTK network corrections, and connect to the Internet via comprehensive communication options. With a built-in transmit/receive UHF radio, the Trimble R8 enables ultimate flexibility for rover or base operation. As a base station, the internal NTRIP caster provides you customized access[1] to base station corrections via the Internet.

Trimble's exclusive Web UI™ eliminates travel requirements for routine monitoring of base station receivers. Now you can assess the health and status of base receivers and perform remote configurations from the office. Likewise, you can download post-processing data through Web UI and save additional trips out to the field.

AN INDUSTRY LEADING FIELD SOLUTION

If you're seeking the industry leading field solution, pair the Trimble R8 GNSS receiver with one of our powerful Trimble controllers, such as the Trimble TSC3, Trimble CU or Trimble Tablet Rugged PC featuring Trimble Access™ field software. These rugged controllers bring the power of the office to the field through an intiutive Windows-based interface.

Trimble Access field software offers numerous features and capabilities to streamline the flow of everyday surveying work. Streamlined workflows such as Roads, Monitoring, Mines, and Tunnels—guide crews through common project types and allows crews to get the job done faster with less distractions. Survey companies can also implement their unique workflows by taking advantage of the customization capabilities available in the Trimble Access Software Development Kit (SDK).

Need to get data back to the office immediately? Benefit from real-time data sharing via Trimble Access Services, now available with any valid Trimble Access maintenance agreement.

Back in the office, seamlessly transfer your field data using Trimble Business Center. Edit, process, and adjust collected data with confidence.

The Trimble R8 GNSS system—the industry leader for GNSS surveying applications.

1 Cellular modem required.

Trimble.

TRIMBLE R8 GNSS SYSTEM

DATASHEET

PERFORMANCE SPECIFICATIONS

Measurements

- Advanced Trimble Maxwell 6 Custom Survey GNSS chips with 440 channels
- Future-proof your investment with Trimble 360 tracking
- High precision multiple correlator for GNSS pseudorange measurements
- Unfiltered, unsmoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response
- Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth
- Signal-to-Noise ratios reported in dB-Hz
- Proven Trimble low elevation tracking technology
- Satellite signals tracked simultaneously:
  - GPS: L1C/A, L1C, L2C, L2E, L5
  - GLONASS: L1C/A, L1P, L2C/A, L2P, L3
  - SBAS: L1C/A, L5 (for SBAS satellites that support L5)
  - Galileo: E1, E5A, E5B
  - BeiDou (COMPASS): B1, B2
- SBAS: QZSS, WAAS, EGNOS, GAGAN
- Positioning rates: 1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz

POSITIONING PERFORMANCE[1]

Code differential GNSS positioning

Horizontal . . . . . . 0.25 m + 1 ppm RMS
Vertical . . . . . . 0.50 m + 1 ppm RMS
SBAS differential positioning accuracy[2] . . . . . . typically <5 m 3DRMS

STATIC GNSS SURVEYING

High-precision static

Horizontal . . . . . . 3 mm + 0.1 ppm RMS
Vertical . . . . . . 3.5 mm + 0.4 ppm RMS

Static and FastStatic

Horizontal . . . . . . 3 mm + 0.5 ppm RMS
Vertical . . . . . . 5 mm + 0.5 ppm RMS

POSTPROCESSED KINEMATIC (PPK) GNSS SURVEYING

Horizontal . . . . . . 8 mm + 1 ppm RMS
Vertical . . . . . . 15 mm + 1 ppm RMS

REAL-TIME KINEMATIC SURVEYING

Single Baseline <30 km

Horizontal . . . . . . 8 mm + 1 ppm RMS
Vertical . . . . . . 15 mm + 1 ppm RMS

NETWORK RTK[3]

Horizontal . . . . . . 8 mm + 0.5 ppm RMS
Vertical . . . . . . 15 mm + 0.5 ppm RMS
Initialization time[4] . . . . . . typically <8 seconds
Initialization reliability[4] . . . . . . typically >99.9%

1 Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. The specifications stated recommend the use of stable mounts in an open sky view, EMI and multipath clean environment, optimal GNSS constellation configurations, along with the use of survey practices that are generally accepted for performing the highest-order surveys for the applicable application including occupation time appropriate for baseline length. Baselines longer than 30 km require precise ephemeris and occupations up to 24 hours may be required to achieve the high precision static specification.
2 Depends on SBAS system performance.
3 Network RTK PPM values are referenced to the closest physical reference station.
4 May be affected by atmospheric conditions, signal multipath, obstructions and satellite geometry. Initialization reliability is continuously monitored to ensure highest quality.
5 Receiver will operate normally to –40 °C, internal batteries are rated to –20 °C, optional internal GSM modem operates to -30 °C.
6 Tracking GPS, GLONASS and SBAS satellites.
7 Varies with temperature and wireless data rate. When using a receiver and internal radio in the transmit mode, it is recommended that an external 6 Ah or higher battery is used.
8 Varies with terrain and operating conditions.
9 Bluetooth type approvals are country specific.

HARDWARE

Physical

Dimensions (WxH) . . . . . . 19 cm x 10.4 cm (7.5 in x 4.1 in), including connectors
Weight . . . . . . 1.52 kg (3.35 lb) with internal battery, internal radio with UHF antenna
3.81 kg (8.40 lb) items above plus range pole, controller, and bracket

Temperature[5]
Operating . . . . . . –40 °C to +65 °C (–40 °F to +149 °F)
Storage . . . . . . –40 °C to +75 °C (–40 °F to +167 °F)
Humidity . . . . . . 100%, condensing
Water/dustproof . . . . . . IP67 dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)
Shock and vibration . . . . . . Tested and meets the following environmental standards:
Shock . . . . . . Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
Vibration MIL-STD-810F, FIG.514.5C-1

Electrical

- Power 11 V DC to 28 V DC external power input with over-voltage protection on Port 1 (7-pin Lemo)
- Rechargeable, removable 7.4 V, 2.6 Ah Lithium-ion battery. Power consumption[6] is 3.2 W in RTK rover mode with internal radio and Bluetooth in use.
- Operating times on internal battery:[7]
  - 450 MHz receive only option . . . . . . 5.0 hours
  - 450 MHz receive/transmit option (0.5 W) . . . . . . 2.5 hours
  - Cellular receive option . . . . . . 4.7 hours

Communications and Data Storage

- Serial: 3-wire serial (7-pin Lemo) on Port 1; full RS-232 serial on Port 2 (Dsub 9 pin)
- Radio modem: fully integrated, fully sealed internal 450 MHz receiver/transmitter option:
  - Transmit power: 0.5 W
  - Range[8]: 3–5 km typical/10 km optimal
- Cellular: fully integrated, sealed internal GSM/GPRS option
- Bluetooth: fully integrated, fully sealed 2.4 GHz communications port (Bluetooth®)[9]
- External communication devices for corrections supported on Serial and Bluetooth ports
- Data storage: 56 MB internal memory, 960 hours of raw observables (approx. 1.4 MB/day), based on recording every 15 sec from an average of 14 satellites

Data formats

- CMR: CMR+, CMRx input and outputs
- RTCM: RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1 input and outputs
- Other outputs: 23 NMEA outputs, GSOF, RT17 and RT27 outputs, supports BINEX and smoothed carrier

Web UI

- Offers simple configuration, operation, status and data transfer
- Accessible via Serial and Bluetooth

Supported Trimble Controllers

- Trimble TSC3 controller, Trimble CU controller, Trimble Tablet Rugged PC

Certifications

FCC Part 15 (Class B device), 22, 24, 90; CE Mark; C-Tick; 850/1900 MHz; Class 10 GSM/GPRS module; Bluetooth EPL

Specifications subject to change without notice.

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APPENDIX H

SMART Assessments

Table H1: SMART Assessment for Legal Requirements	
Criteria	**Assessment**
Specific	
Related to intent?	Yes, the assessment table for legal requirements will provide the evaluator with an understanding of what must be completed before the commercial use of a UAV can begin.
Linked to requirements?	Yes, the results of the assessment table help the organization understand their legal responsibilities, and the approximate cost of fulfilling them.
Measurable	
Readily available?	CASRs and advisory circulars are readily available from CASA's website.
Available data sufficient?	Yes, legal responsibilities can be completely understood using the CASRs and advisory circulars.
Acquisition practical?	Yes, acquisition of the required information does not require any special effort.
Process repeatable?	Yes.
Achievable	
Cost effective?	This indicator requires very little input.
Realistic effort?	Yes, requires very little input.
Who will gather data?	The surveyor/manager performing this evaluation or one of his subordinates/somebody in his employ
Who will analyse data?	The surveyor/manager performing this evaluation or one of his subordinates/somebody in his employ; contacting CASA may be necessary if the legislation is confusing to the evaluator.
Relevant	
Relevant to project aims?	Yes, this assessment will ensure that the evaluator understands that the user of a UAV has a legal responsibility and will enable them to compare the costs of certification with the benefits.
Timely	
Data available when required?	Yes, legislation is published online and CASA has a contact service center.

Table H2: SMART Assessment for Efficiency	
Criteria	**Assessment**
Specific	
Related to intent?	Yes, comparing efficiency will provide additional justification to the UAV's appropriateness, or inappropriateness for the particular task.
Linked to requirements?	Yes, comparing efficiency in this manner will identify any direct benefit to the business (i.e. a reduction in costs), and therefore determine success or failure in this objective.
Measurable	
Readily available?	Most likely not; information will need to be gathered during a test run – however, this test run will also provide data for other indicators used in the evaluation.
Available data sufficient?	The data gathered during the experiment will be sufficient for this indicator.
Acquisition practical?	Acquisition is practical, but will require special effort to organize a test flight
Process repeatable?	Depends on the application the UAS is being tested for, but in general the task can probably be repeated (i.e. coal stockpiles surveys are a standard task).
Achievable	
Cost effective?	When the capital cost of the UAS is considered along with the effort required for certification, it becomes clear that performing a test flight is necessary before making a purchase, to ensure it is truly fit for purpose.
Realistic effort?	If the experiment provides data that can be used to determine accuracy and usability, as well as efficiency, then the effort becomes realistic.
Who will gather data?	If no one in the organization is certified then the gathering of data will require: - A UAV controller to operate the UAV - The evaluator to record observations

Who will analyse data?	Once the data has been acquired, the evaluator alone can perform the required calculations and analysis
Relevant	
Relevant to project aims?	Yes, efficiency is a major factor in determining the appropriateness of the UAS.
Timely	
Data available when required?	The experiment can be timed to suit all parties involved.

Table H3: SMART Assessment for Accuracy	
Criteria	**Assessment**
Specific	
Related to intent?	Yes, accuracy may be a deciding factor when determining what the UAS can be used for.
Linked to requirements?	Yes, understanding the accuracy that is obtainable from a UAS will immediately decide if the UAS can or cannot be used in the desired application.
Measurable	
Readily available?	No, data will need to be acquired using a UAS and then analysed using the correct approach.;
Available data sufficient?	No, data is not readily available.
Acquisition practical?	Data acquisition depends on a UAS being available for a trial, unless data/results are made available by another organization.
Process repeatable?	The survey may be easily repeatable, however exact conditions will be difficult to reproduce.
Achievable	
Cost effective?	Considering the capital cost of a UAS, it is crucial to determine how well the UAS can achieve the accuracy requirements of the intended application.
Realistic effort?	Yes, the trial run should not exceed the expectations of a normal job/normal working conditions.
Who will gather data?	If no one in the organization is certified then the gathering of data will require: - A UAV controller to operate the UAV - Surveyor to analyse results - The evaluator to record observations
Who will analyse data?	The results will need to be analysed by someone with suitable/appropriate knowledge, i.e. a surveyor or other professional who is capable of producing the required output, and understands

	accuracy and precision and how to measure it.
Relevant	
Relevant to project aims?	Yes, accuracy is an important factor for determining if the UAS can be used in a specific application.
Timely	
Data available when required?	The experiment can be timed to suit all parties involved

Table H4: SMART Assessment for Efficiency	
Criteria	**Assessment**
Specific	
Related to intent?	Yes, the evaluation of usability will provide valuable insights into the practical issues of using a UAS for surveying.
Linked to requirements?	Yes, the SUS evaluation is robust enough to determine if the UAS is better to use than other surveying equipment.
Measurable	
Readily available?	No, in order for the UAS to be rated on the SUS scale, then the evaluator must use the UAS for a survey.
Available data sufficient?	There is no data available before the UAS is actually used and evaluated.
Acquisition practical?	The SUS evaluation is very easy to apply and once the evaluator has used the UAS, they will be able to apply the SUS scale immediately.
Process repeatable?	The process is repeatable but because usability is subjective, the results may not be consistent or accurate when using a small sample size.
Achievable	
Cost effective?	Performing an SUS evaluation costs nothing and requires very little effort.
Realistic effort?	Yes, SUS evaluation requires limited effort.
Who will gather data?	If no one in the organization is certified then using the UAS will require: - A UAV controller to operate the UAV - The evaluator to record observations
Who will analyse data?	The results of the SUS can be easily reduced by the evaluator, without any specific technical knowledge.
Relevant	
Relevant to project aims?	Yes, determining the ease-of-use is an important factor for understanding how effectively the UAS can be used by surveyors.
Timely	

Data available when required?	The evaluation can be performed whenever there is a UAS available for demo.